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TORQUE SENSING USING AMORPHOUS MAGNETOSTRICTIVE WIRES

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In this paper we present experimental results on the torsional dependence of amorphous magnetostrictive wires by using three different magnetic techniques in order to evaluate and compare them, namely magnetostrictive delay line, the stress-impedance and the domain wall nucleation and propagation techniques. We determined monotonic response in the stress-impedance and domain wall nucleation and propagation set-ups even in the as cast form. Concerning the magnetostrictive delay line, induced magnetic anisotropy was required to obtain monotonic response. The most sensitive response was obtained by using the delay line technique, although the power consumption was higher.

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1. Introduction

Sensors have an increasing interest because of their importance in many technological applications [1]. Automotive applications of sensing elements are of increasing significance in passive or active safety processes. Road traffic accidents are a major proportion of accidents in general, which is why the use of sensors in modern cars is continuously increasing, there being more than 1500 sensing elements per car nowadays. Sensors based on magnetic materials govern some of these applications [2]. A GMI field sensor has been used to control the position of a car [3-4], for cruising and parking modes. Car engine applications, like misfiring determination, of torque sensing have also been proposed [5]. Industry is also employing sensors for the monitoring and control of production lines. The main field in industrial applications is the non-destructive testing and evaluation that require the use of small field sensors. Another major field of industrial applications is the position, velocity and acceleration/vibration controllers [6]. Interesting studies on the use of magnetostrictive materials as actuating elements has also been presented [7].

A vast variety of torque sensors has been realized [8]. One principle is the use of pre-annealed magnetic materials under torsion. The MI effect and the MDL set-up have been proposed in as torque meters, with very competitive properties, accuracy and low cost. Flow sensors based on electromagnetic techniques are well known in industry. Recently, flow meters have also been proposed, using the effect of bending stress on an amorphous wire [9].

In this paper we present experimental results on the torsional dependence of amorphous magnetostrictive wires by using three different magnetic techniques, namely the magnetostrictive delay line (MDL), the stress-impedance and the domain wall nucleation and propagation (DWN), in order to evaluate and compare them for the development of inexpensive and accurate torque sensors. MDL technique is related to the ability of the amorphous wires to be used as sensing elements due to their good magnetic and magnetoelastic properties [10]. Stress-Impedance technique uses the magneto-inductive (MI) effect and is based on the good response of these materials under tensile and torsional stress [11]. DWN technique is based on domain wall propagation; the low velocity of these walls as well as their relatively large width, allows the use of low cost electronics, without loss of sensitivity and linearity [12].

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2. Experimental set-up

Concerning the MDL set-up, a three-part outer cell was used for sensor encapsulation as well as for transducing the applied torque to sensing material [13]. The three cells were cylinders and were connected with a horizontal bronze bearing in order to allow torsional stress to be applied to the wires. The outer cylinders were used to support the ends of the sensing material by means of two threaded holes. A stress-free magnetostrictive wire was fixed at the two ends of the outer cell by means of two fixing screws, allowing the controllable realization of tensile stress along the length of the wire. The outer cylinder was containing the exciting/receiving coil, while these coils were covered by a permanent magnetic cylinder and a soft magnetic alloy for shielding purposes. The outer cylinder also was containing the electronic circuitry for excitation of the MDL wire and the circuitry for the detection and conditioning of sensor output (see Fig. 1a).

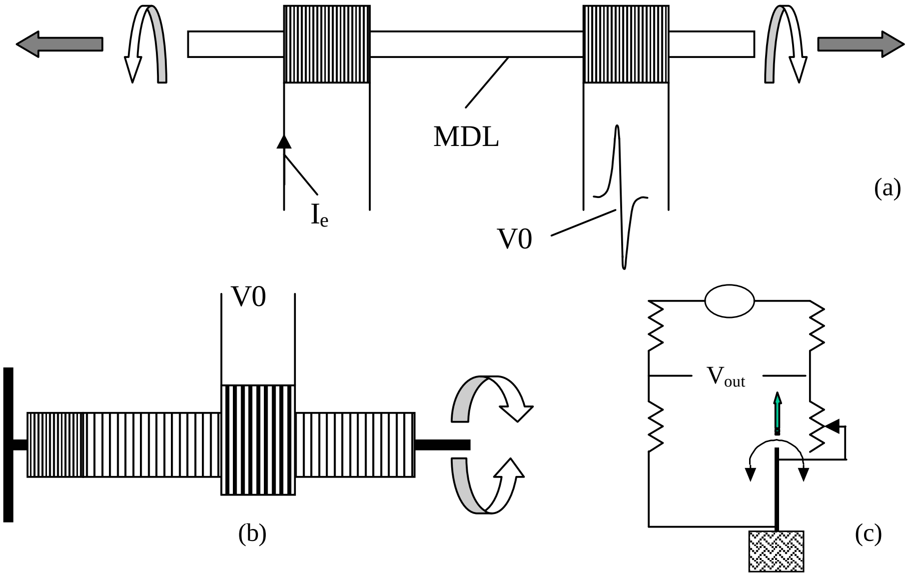


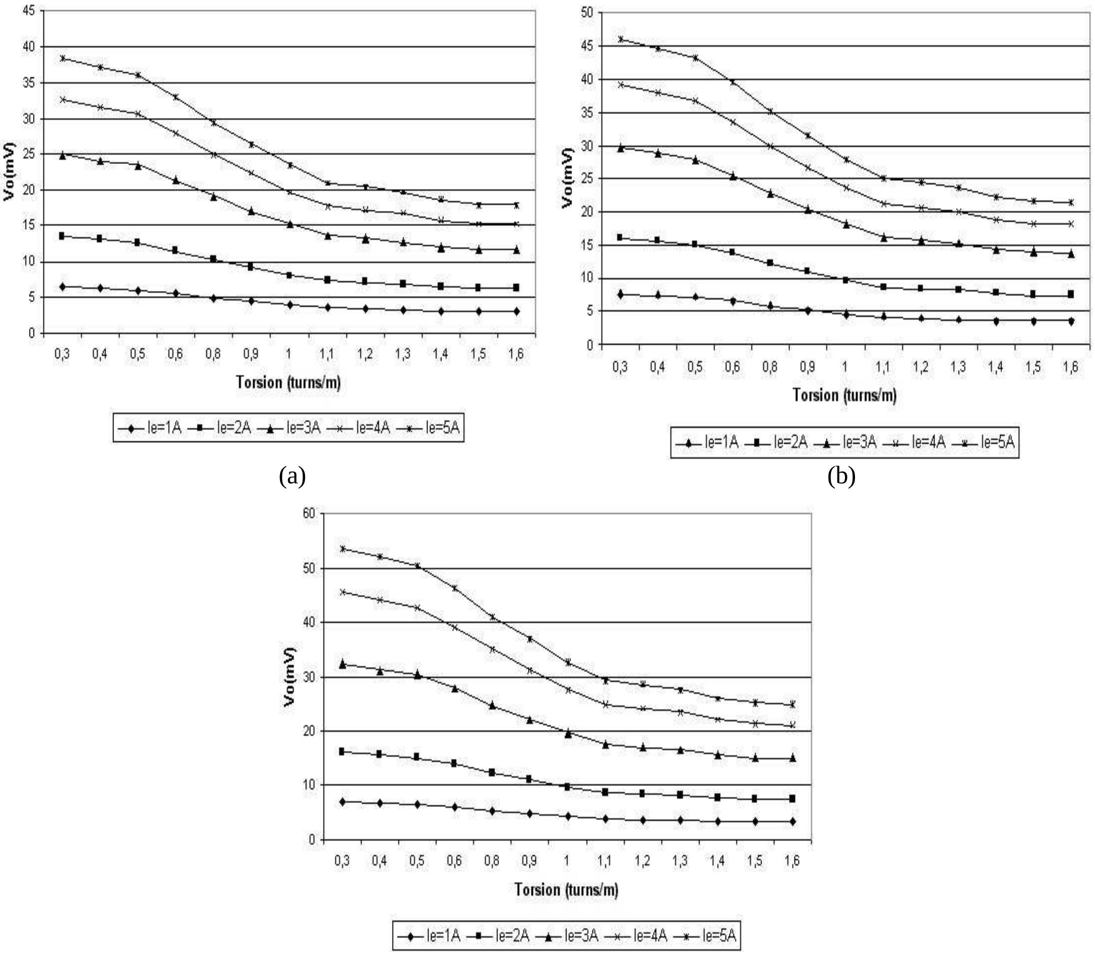
Fig. 1. The experimental set-up.

For the Domain wall set-up an amorphous wire was surrounded by two detecting coils [14]. One coil is used for excitation and the other for signal detection. The peak to peak pulsed output voltage V0 was the sensor output. A pulse generator was used for biasing the wire and nucleating a domain wall. Nucleation of domain wall was obtained by passing pulsed current through the exciting coil and was detected by the outputs of the search coil (see Fig. 1b). The Stress-impedance experimental set up was similar MDL set-up concerning the outer cell, the cylinders, the stress-free wire and the electronic circuitry [15]. The magneto-inductive wire was surrounded by a permanent magnetic cylinder for biasing purposes and a soft magnetic alloy for shielding purposes (see Fig. 1c).

3. Results and discussion

The magnetostrictive wires were tested in the as-cast form, after a stress-relief process and after flash stress current annealing. A pulse generator used for flash annealing. Pulsed current is transmitted through the wire and is monitored by a high precision resistance connected in-series with the wire. The stress-relief process conditions were 300 °C for 30 min. The flash stress current annealing conditions were 1A, 10ms, pulse duration of 50% duty cycle for 10s.

The dependence of the MDL torque response is illustrated concerning the three testing cases of wires in Figs. 2a, 2b and 2c respectively. The dependence of the DWN torque response is illustrated concerning as-cast, stress-relief and flash current annealed wires in Figs. 3a, 3b and 3c respectively. The dependence of the MI torque response is illustrated concerning as-cast, in figure 4. Concerning the response of DWN and MI sensors, it can be observed that their response is monotonic, which mainly means that a given voltage output of a calibrated sensor can be the indication of one and only one applied torque. Concerning the MDL sensors, induced magnetic anisotropy by flash current annealing was required to obtain monotonic response.



(a)

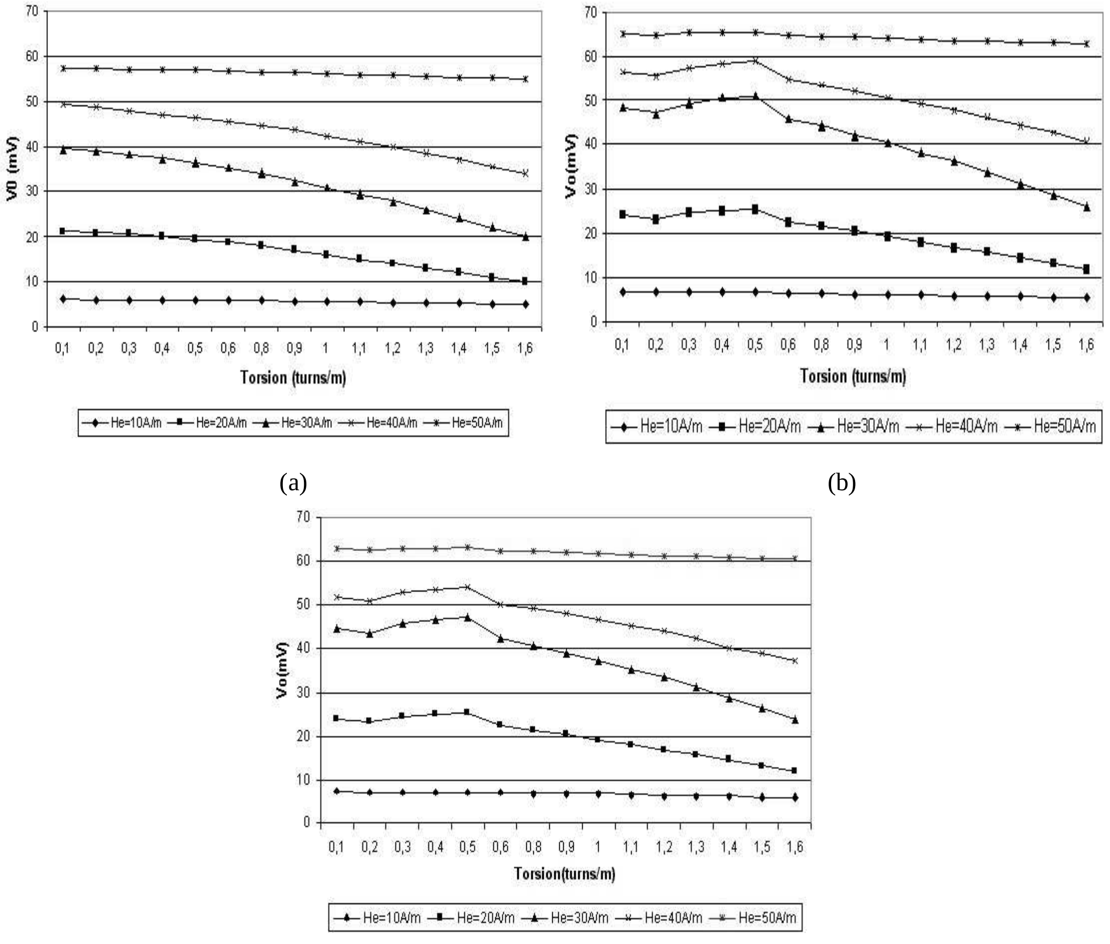
(b)

(c)

Fig. 2. The dependence of the MDL torque response.

The sensitivity of the sensors which is defined as the ratio of the minimum applied input for which an incremental voltage output can be obtained, depends on of the technique used and the history of the material. For torque sensors based on the DWN technique the sensitivity of the wires for the case of (i) as cast materials varies from 1,5 to 0,5 turns/m/mV, (ii) after stress-relief materials varies from 1,3 to 0,33 turns/m/mV, (iii) after flash stress current annealing materials varies from 1,4 to 0,17 turns/m/mV. For torque sensors based on the MDL technique the sensitivity of the wires for the case of (i) as cast materials varies from 0,8 to 0,027 turns/m/mV, (ii) after stress-relief materials varies from 0,6 to 0,022 turns/m/mV, (iii) after flash stress current annealing materials varies from 0,6 to 0,018 turns/m/mV. For load cells based on the stressimpedance technique the sensitivity of the wires for the case of as cast materials varies from 1 to 0,1 turns/m/mV. Concluding the more sensitive response was obtained by using the MDL technique, although the power consumption was higher for that case.

The repeatability of the sensors is mainly affected by the repeatability of the magnetic materials used, since micromachining and electronic circuit techniques are well known. Thus the repeatability of signals response in magnetostrictive wires is mainly affected by the magnetoelastic uniformity of the wires. This has been studied in the past and has been resolved of repeatable response after stress relief and stress annealing of the tested wires [16]. The major problem of protection against the ambient field in sensors based on soft magnetic materials, is realized by shielding the critical points of sensors by soft magnetic alloys [17]. Such sensors applications can be realized after miniaturization process [18] and after solving the problem of material aging [19].



(a) (b)

(c)

Fig. 3. The dependence of the DWN torque response.

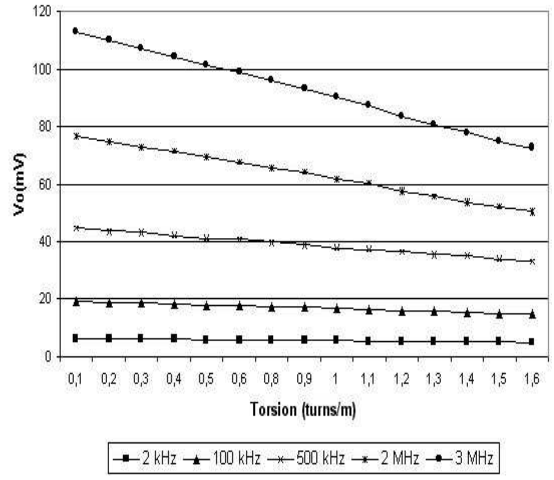


Fig. 4. The dependence of the MI torque response on torsion.

4. Conclusions

Amorphous magnetostrictive wires were examined due to torsional dependence by using magnetostrictive delay line (MDL), stress-impedance and domain wall nucleation and propagation (DWN). The before mentioned techniques evaluated and compared for the development of inexpensive and accurate torque sensors. The response of DWN and MI sensors was monotonic while for MDL sensors, induced magnetic anisotropy by flash current annealing was required. The more sensitive response was obtained by using the MDL technique.

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