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A new magnetoelastic device for sensing applications

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Abstract

In this paper a new magnetostrictive delay line set-up for sensor applications is proposed. The tri-layer set-up consists of an inner cylindrical copper core, an intermediate thin insulating layer and an outer circumferential magnetoelastic thin film. Packaging reasons require a coating-insulating layer on top of the set-up. Different Fe–Ni compositions have been tested for the magnetostrictive film. Characterization of the devices showed that negative magnetostrictive film operates as a magnetostrictive delay line set-up, even without magnetic and heat treatment. Concerning positive magnetostrictive films, heat treatment was necessary to allow the propagation and detection of the elastic pulses.

Keywords: Magnetoelasticity; Thin films; Magnetostrictive delay lines

1. Introduction

The magnetoelastic devices have been used for many sensing applications [1]. Among them, the magnetostrictive delay line (MDL) technique has also been used for the realization of sensing elements like position and stress sensors, load-cells, pressure gauges, etc. [2]. In fact, the MDL technique has also been used for the industrial development and commercialization of position sensors based on the measurement of the delay time between micro-strain points of origin and detection respectively. Furthermore, there is an increasing interest towards the realization of more sophisticated sensors based on this technique, able to measure mechanical quantities with competitive levels of uncertainty [3]. At this moment, this is realized by using hybrid sensing elements with hybrid accompanying electronic circuitry.

In order to increase the manufacturing scale and the repeatability of properties, the human factor in production ought to be minimized. One way to obtain that is the development of devices, able to be produced in automated production lines. For the case of MDLs, the thin film technology is a promising way of obtaining this target.

Having as motivation the above mentioned targets, a magnetoelastic device has been conceived, which is able to operate as MDL. In the following text, the device is described as well as the manufacturing process is analyzed taking into account its microstructure and its ability or disability to operate as MDL. Finally, the basic MDL characteristics are illustrated and discussed.

2. The magnetoelastic device

The schematic of the magnetoelastic element is illustrated in Fig. 1. A cylindrical conductor is used as the substrate for an insulating layer, on which a cylindrical magnetostrictive film is deposited. Passing pulsed current through the inner conducting wire results in transmitting pulsed circumferential magnetic field to the outer magnetoelastic film. Such field results in local micro-elongations or stresses due to the magnetostriction effect which, more or less, cancel each other due to the magnetoelastic uniformity of the outer film.

Local break of the magnetic symmetry results in a local break of the symmetry of the dynamic micro-strains, as depicted in Fig. 2, thus generating an elastic pulse, which propagates along the length of the film, provided that such a propagation can take place. The propagating pulse can be received by means of a pulsed voltage output induced in a search coil at the one end of the device, due to the inverse magnetostriction effect. The time position of this pulsed voltage indicates the position of the

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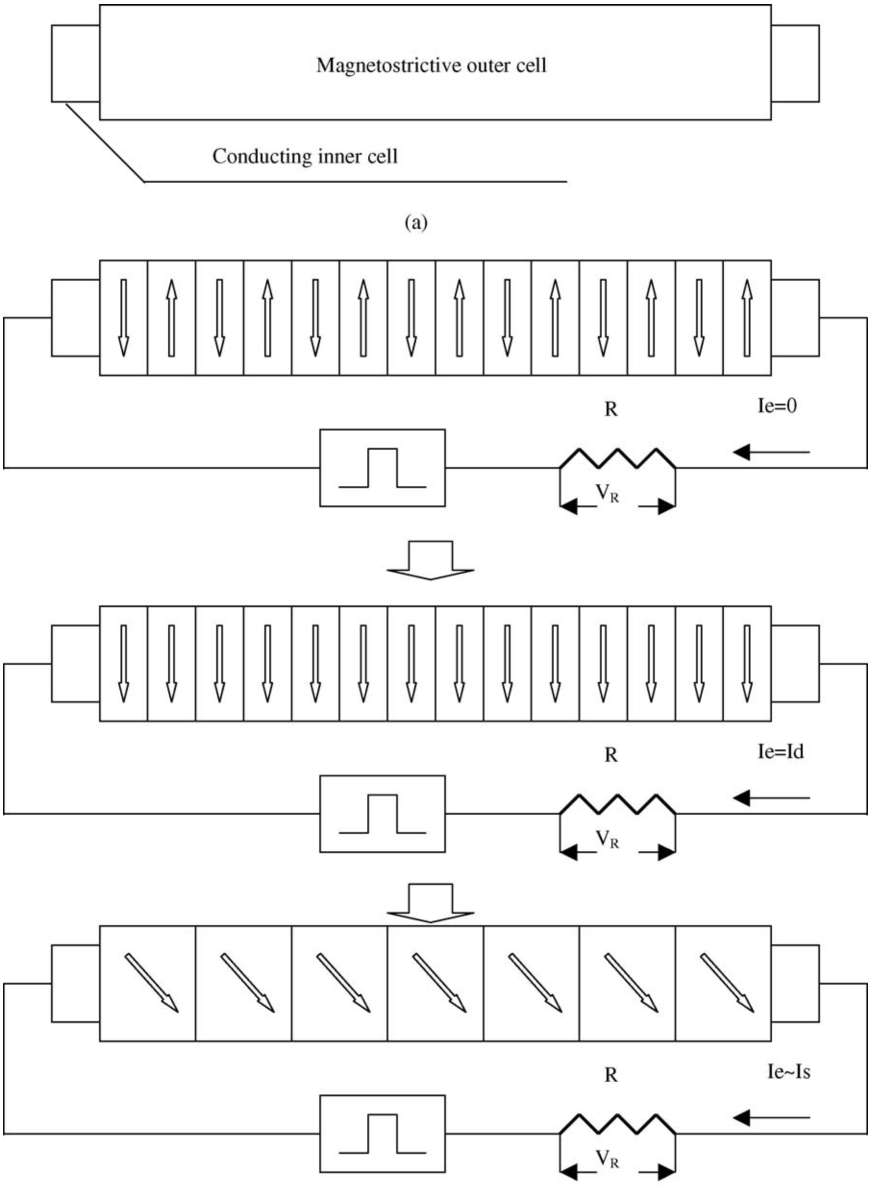

(a)

(b)

Fig. 1. The MDL device.

magnet and its amplitude indicates the amplitude of the local magnetic field non-symmetry. This effect can be caused by a small permanent magnet travelling along the length of the device or by a local magnetic field anomaly. Therefore, such a device can be used as position/displacement sensor or distribution NDT sensor on magnetic surfaces.

The realization of such a device took place in three steps. The first step was the development of the insulating interface layer between the conductor core and the magnetoelastic film. Although at the beginning this has been obtained by using a 0.1 mm copper wire thermally oxidised at ∼550 °C for 10 min, thus resulting in a relatively thin oxide layer, with acceptable geometrical characteristics, for repeatability and automatic production purposes, a magnetron sputtering device was used to deposit SiO_2 film on the same 0.1 mm copper wire. The measurements of this oxide film thickness using cross section metallographic microscopy, show a thickness of 1 μm ± 10 nm, which is considered as acceptable.

Next step was the deposition of the magnetostrictive circumferential thin film, using the same magnetron sputtering facility. The first experiments were realised by depositing Fe–Ni alloys. The geometrical uniformity of the cross section of the films was also determined by cross section metallographic microscopy and was found to be 1 μm ± 20 nm. XRD structural characterization on the powder of the deposited magnetostrictive film indicated amorphous state. Elementary magnetoelastic measurements where performed in parallel with the structural characterization using SEM in order to determine the optimum conditions of films. It was found that the most significant structural problem was the generation of cracks on the magnetoelastic film. For the films having surface cracks like the ones illustrated in Fig. 3, the elastic pulses could not propagate with acceptable