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Amorphous wire based stress sensor working with low carrier frequency

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Abstract

Impedance spectroscopy methodology is used in this article to evaluate the influence of axial applied stress on complex impedance components of as cast CoFeBSi wires in the 100 Hz to 300 kHz frequency range, at 10 mA ac current. Based on the obtained results, problems of practical significance are discussed since the envisaged application is the construction of sensitive stress sensors for detection of such as pressure, tension and stream speed for liquid and gases.

Key words: internal ac impedance, stress-impedance effect, amorphous materials, impedance spectroscopy

1. Introduction

Co-rich amorphous alloys are known to be very attractive systems to study their peculiar magnetic behaviour and also their potential applications. These quasi non-magnetostrictive materials presents stress and field induced anisotropies, high sensitivity to composition, thermal treatments and applied mechanical stress and severe dependencies on external magnetic field.

Due to their promising technological applications in growing areas such as the design and development of small and micro sensors for magnetic fields, sensors for mechanical stress, strain or torsion detection and measurement, the study of these materials has become a topic of increasing interest. Some of the most promising results have been obtained by using the magneto-impedance (MI) effect - a large change of impedance that occurs in a ferromagnetic material when it is submitted to a magnetic field, and when an ac current is flowing through the sample. This behaviour is a consequence of the skin effect, that at high frequencies (tens of kHz), changes the effective current path cross section area inside the sample. Since the skin effect depends on the magnetic properties of the material through the magnetic permeability, it can be understood that it is strongly influenced by magnetic fields, tensile and torsional stresses, annealing treatments, or other factors that change the domain structure and magnetic properties of the material.

Some papers are addressing the stress dependencies as stress-impedance (SI) effect, the mechanism being explained by the small negative magnetostriction coefficient of CoSiB wire. Hence, axial effort induces radial and circumferential easy directions and makes the magnetic moments rotate to these directions. To reduce the magnetostatic energy circumferential easy direction is preferred since it provides a natural closure path. Owing to this the bamboo domain will grow wider and deeper into the core until the wire saturates.

In order to evaluate the possibilities to use this magnetic wire as the sensitive element of the mechanical effort sensor we used complex impedance formalism and impedance spectroscopy measurement technique instead of global magnetoimpedance ratio. This technique gives us more flexibility and also the opportunity to analyze each component of the internal ac impedance of the wire. Moreover it allows simple physical interpretation and correlation since the two components of the complex impedance can be related with distinct and still connected mechanisms. The real part of impedance is related to the sample electrical resistance, and the imaginary component is related to the inductance, and therefore to the magnetic permeability. The dependence of these components with the applied stress in the axial direction has been studied in the sample, for the frequency domain 100 Hz to 300 kHz. This frequency domain was selected because it covers both low frequencies, where the magnetization is mostly due to domain wall movements, and high frequencies where the dominant magnetization process is the moment rotation.

2. Experimental Setup

We used as-quenched amorphous wire of nominal composition $(Co_{94}Fe_6)_{72.5}B_{15}Si_{12.5}$, 130 μm diameter prepared by the in-water-rotating technique. The sample, with 5 cm. length, was mounted in a special sample holder with firm electrical contacts, enabling the application of controlled tensile stress. Impedance measurements were carried out by means of a system build with a Novocontrol analyzer (Alpha type) controlled by a PC. We used the manufacturer's recommended configuration [8] special attention being paid to the impedance compensation of the line from the analyzer impedance inputs to the sample. The inductivities L_S and resistors R_S of the BNC lines contributing as a additional serial impedance to the measured one were taken into account using load short calibration and line compensation procedures. Because of the low value of the measured impedance, the R_P resistor has been considered large enough to be neglected. Also the capacitances C_P are requesting no compensation since they are eliminated by the virtual ground technique of the current input amplifier.

All data were measured at room temperature with wire axis established at 90 degrees in respect with earth's field. The ac current through the amorphous wire was kept constant (10 mA), and complete spectroscopic measurements were done at frequencies from 100Hz to 300 kHz. Tensile stress from 0 to 333 MPa (0, 74, 133, 260 and 333) was axially created using calibrated weights.

The results have been processed using some specific virtual instruments developed in LabVIEW graphical programming environment

3. Results

The purpose of this paper is to explore the possibilities to build force sensors using the peculiar magnetic behaviour of $(Co_{94}Fe_{6})_{72.5}B_{15}Si_{12.5}$ amorphous wire and therefore the experimentally acquired data have been processed in order to emphasize the dependencies of several complex impedance parameters on axial applied stress. The results are presented in Fig. 1 to Fig.3.

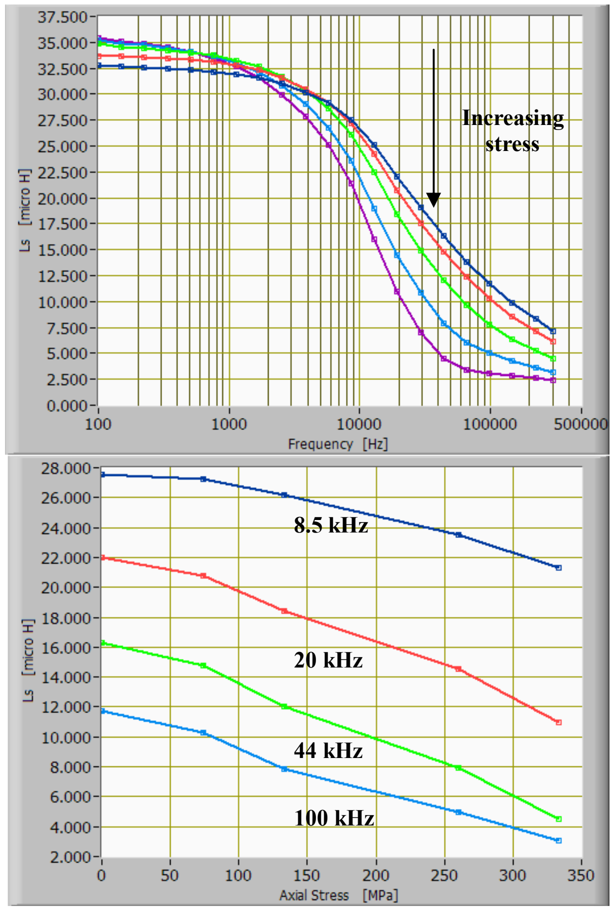

Fig. 1. Internal serial inductance of the amorphous wire

The dependence of the internal serial inductance of the amorphous wire on ac current frequency and applied axial stress is represented in Fig.1. The upper graph is reflecting the frequency behaviour for five different values (0, 74, 133, 260 and 333 MPa) of tensile stress while the lower one is reflecting the stress behaviour for four ac current frequencies. As resulting from these graphs severe dependencies are emphasized, proving the existence of a magnetoelastic coupling between magnetostriction and internal stresses arised during the manufacturing process. Changes in inductance value up to 75% for the analyzed stress domain reveal that very sensitive stress sensors can be constructed based on this variation, with an ac carrier current frequency somewhere between 40 kHz and 100 kHz.

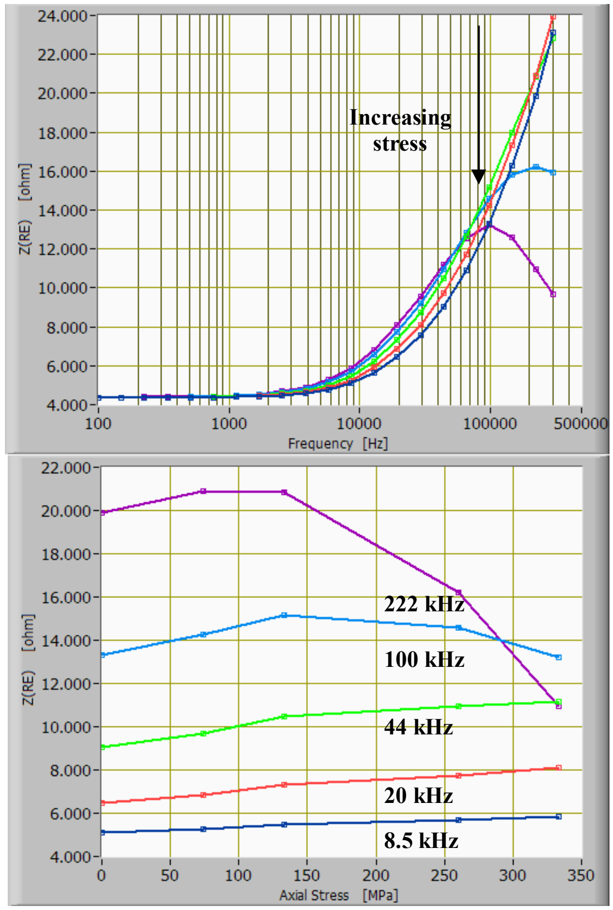

Fig. 2. Real component of the complex impedance

In Fig. 2 are reported the results obtained for real (resistive) component of the complex impedance of the wire. In contrast with the inductance of the wire, its resistance exhibit variation of only 15-18% with good linearity. For higher frequencies the dependence curves are highly nonlinear.

Interesting results, depicted in Fig. 3, have been obtained for phase angle between magnetizing current and end-to-end sample voltage. Up to 82% variation for the analyzed stress domain were found for this parameter. These results, obtained for a relative low frequency ac current frequency (44kHz), indicate that a whole new class of stress sensors can be developed.

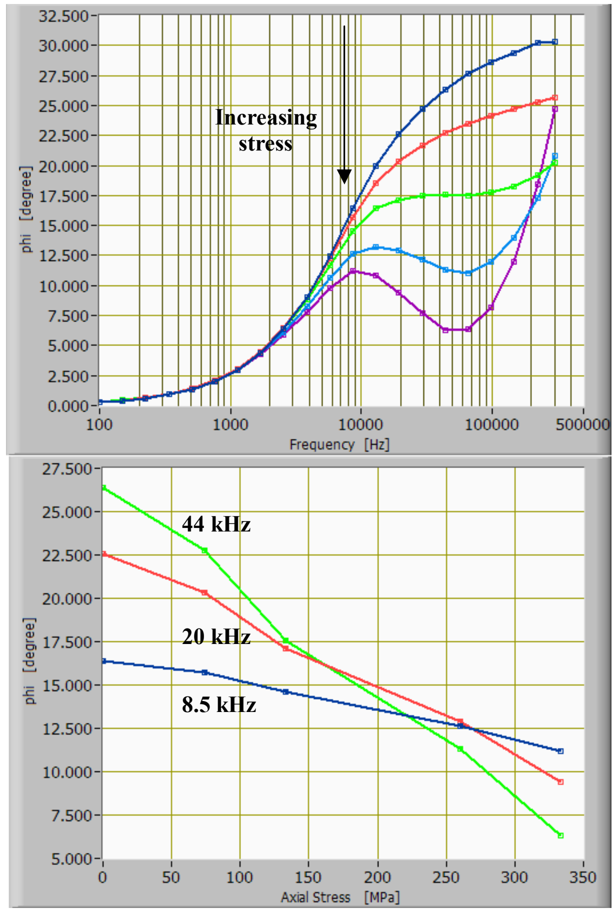

Fig. 3. Phase angle between magnetizing current and end-to-end sample voltage

4. Conclusion

The frequency response of complex inductance in as-cast $(Co_{94}Fe_{6})_{72.5}B_{15}Si_{12.5}$ wires, here presented, highlighted the possibility of developing new sensitive stress sensors. Being the relative low ac current frequency (40 kHz – 50 kHz) both amplitude components (inductance and resistance) and also phase component can be used.

Acknowledgments

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