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# Effects of torsion stress on the domain wall unpinning AC field in amorphous FeCoBSi wires

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**Abstract**

The unpinning or propagation field, $h_p$, where domain walls are unpinned and start their displacement under the AC magnetic field of as-cast amorphous wires of nominal composition $(Co_{94}Fe_6)_{72.5}B_{15}Si_{12.5}$, was determined for each torsion angle between –90° (counterclockwise) and +150° (clockwise) at a constant frequency of 1 kHz. A plot of $h_p$ as a function of torsion angle showed a sharp minimum at a torsion angle of +120. The results are interpreted in terms of the counterbalance effect of the torsion against the intrinsic helical anisotropy induced during the wire fabrication.


*Keywords:* Magnetoimpedance; Amorphous wires; Induced anisotropy

## 1. Introduction

Giant magnetoimpedance (GMI) [1,2] has raised a strong interest for its technological applications in magnetic field, DC electric current, and stress sensors, [3,4] among others. The effects of tensile stresses have been addressed [5,6], and there is a growing interest on the effects of torsion [7,8].

In this paper, we present a study of the effects of torsion on the magnetoimpedance response in as-cast Co-rich amorphous wires. The analysis is carried out on the basis of magnetization processes at low frequencies ($f \ll 1$ MHz), where skin depth effect can be neglected.

## 2. Experimental techniques

We used ~10 cm long pieces of as-cast, amorphous wires of nominal composition $(Co_{94}Fe_6)_{72.5}B_{15}Si_{12.5}$ and 125 μm diameter, prepared by means of the in rotating-water quenching technique and kindly supplied by Unitika Ltd Japan. Impedance measurements were carried out using an HP4192A Impedance Analyser system within the frequency range 5 Hz–13 MHz at a current amplitude $i_{rms}$ of 0.2 mA (RMS). The axis wire was oriented perpendicular to the earth's magnetic field.

## 3. Experimental results

We measured the real $Z_r$, and imaginary $Z_i$ parts [$\mathbf{Z} = Z_r + jZ_i$, where $j$ is the basis of imaginary numbers, $j = (-1)^{1/2}$] of the impedance response as a function of frequency. However,

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instead of using the total impedance, $Z_T = (Z_r^2 + Z_i^2)^{1/2}$, we transformed the data into complex permeability, which allows a clear image of magnetic processes involved in GMI [9]. This can be done by considering a cylindrical magnetic conductor of radius $a$. The impedance of a wire can be expressed as [10]

$$\mathbf{Z} = R_{DC}(ka/2)J_0(ka)/J_1(ka), \quad (1)$$

where $R_{DC} = \rho l/\pi a^2 =$ DC resistance, $\rho =$ resistivity, $l$=length of the wire, $k = (1+j)\mu_r^{1/2}/\delta_0$ is the circumferential propagation constant depending on the relative permeability of the conductor, $\mu_r = \mu/\mu_0$, and on the skin depth $\delta_0$ in a nonmagnetic conductor having the same resistivity. $J_0$ and $J_1$ are first-order Bessel functions which satisfy the symmetry and boundary conditions of the cylindrical magnetic conductor. In the low-frequency case, the skin depth is larger than the wire radius and $|ka| \ll 1$. By considering only the first-order terms in an expansion of the Bessel functions, it can be shown that the complex permeability is expressed by $\mu = -2j\times 10^7(\mathbf{Z} - R_{DC})/\omega l$ [10]. Note that the presence of $j$ in this relation leads to a cross-over of terms: real permeability is determined by imaginary impedance, and conversely, imaginary permeability depends on real impedance.

The real part of permeability showed a relaxation behavior as a function of frequency, as we have previously shown, Fig. 1 [11]. When the experiments are carried out under a torsion stress, however, the curves are modified as a whole. We have recently shown [11] that by plotting the value of permeability at constant frequency (at 1 kHz), an asymmetric relation is obtained, with a maximum at a torsion angle of $+120°$. We have also shown [9] that the low-frequency plateau in real permeability is obtained only for low values of AC current amplitude, i.e., for low values of AC magnetic field amplitude, $h_{AC}$. When the AC field amplitude is increased above a certain threshold value, the low frequency value of permeability increases and becomes dependent on $h_{AC}$. This threshold is the unpinning, or propagation field, $h_p$, which marks the field where domain walls are unpinned and become able to displace in the material.

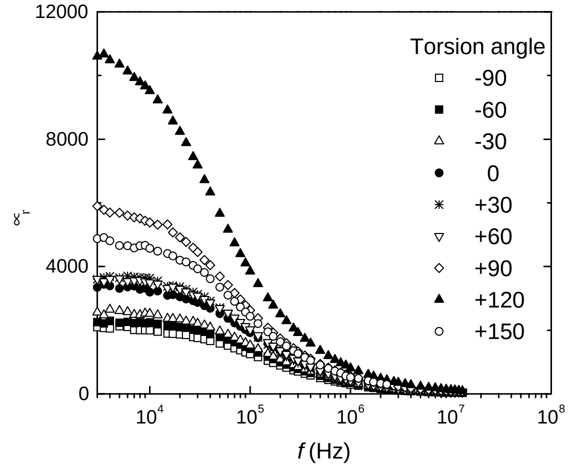


Fig. 1. Real part of permeability as a function of frequency for various torsion angles. The + sign denotes a clockwise turn, and the − sign a counterclockwise turn. The AC current amplitude was 0.2 mA (RMS).

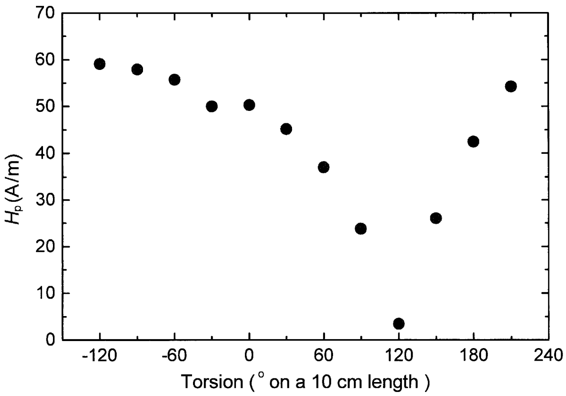


Fig. 2. Propagation field as a function of the torsion angle.

We carried out the experiments as a function of the AC field amplitude for each torsion angle, in order to determine the propagation field as a function of the torsion stress, which is shown in Fig. 2. A sharp minimum is observed for a torsion angle of $+120°$, which is associated with the maximum in real permeability previously observed [11]. These results clearly point out to a helical-induced anisotropy, presumably during the preparation of the samples. The clockwise torsion relieves such anisotropy and compensates it completely at $+120$. The torsion at angles lower than +120, and counterclockwise have the effect of increase in such anisotropy, leading to a decrease in permeability and its associated increase in propagation field.

## 4. Conclusions

The magnetization processes associated with magnetoimpedance can be used to analyze the effects of torsion stresses on ferromagnetic wires. The presence of an induced anisotropy with helical geometry has been found to be minimum in the AC field amplitude needed to unpin and propagate domain walls at a torsion angle different from zero, and is in very good agreement with a maximum observed in permeability for the same torsion angle.

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