

Ferromagnetic Resonance in Cast Microwires and its Application for The Non-Contact Diagnostics

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Abstract

The natural ferromagnetic resonance reveals large residual stresses appearing in the microwire core in the course of casting. These stresses, together with the magnetostriction, determine the magnetoelastic anisotropy. Beside the residual internal stresses, the natural ferromagnetic resonance frequency is influenced by external stresses applied to the microwire or to the composite containing the latter (the so-called stress effect).

The dependence of the natural ferromagnetic resonance frequency on the deformation of the microwires is proposed to be used in the distant diagnostics of dangerous deformations of critical infrastructure objects

Keywords: Cast glass-coated amorphous magnetic microwire; Magnetostriction; Natural ferromagnetic resonance

Theory

The properties of the magnetic glass-coated cast amorphous micro and nanowires studies in many publications by various research groups [1-21]. The phenomenon of natural ferromagnetic resonance (NFMR) in the magnetic glass-coated cast amorphous micro and nanowires [4,6-13] is extremely interesting from the viewpoint of using it for non-contact diagnostics of distant of critical infrastructure objects.

The diagnostics become possible due to the stress effect on the NFMR, that is, the shift of the resonance frequency as a result of a deformation of the object. Such a frequency shift can be measured by irradiating the object with microwaves emitted by radar at frequencies near the NFMR and detecting the reflected signal, thus revealing a deviation of the resonance frequency from the original value.

The glass coating of the cast GCAMNWs induces strong mechanical stresses in the kernel [4]. In cylindrical coordinates, the residual tension is characterized by the axial, s_z , radial, s_r , and tangential,

s_φ , components. The value of these stresses depends on the ratio of the radius, R_m , of the metallic kernel to the total microwire radius, R_c :

$$x = \left(\frac{R_c}{R_m}\right)^2 - 1, \quad (1)$$

Using the cylinder-shell model, we then obtain a formula for stresses in the metallic kernel of the cast GCAMNWs:

$$\sigma_r = \sigma_\phi \equiv P_\nu \quad (2)$$

$$P_\nu = \varepsilon E_1 \frac{kx}{[k(1-2\nu)+1]x+2(1-\nu)} \quad (3)$$

where $\varepsilon E_1 = \sigma_0 \sim 2$ GPa is the maximum stress in the metallic kernel; ε is the difference between the thermal expansion of the metallic kernel and that of the glass shell with the expansion coefficients α_1 and α_2 : $\varepsilon = (\alpha_1 - \alpha_2)(T^* - T)$; is the Young modulus of the metallic kernel, T^* is the solidification temperature of the composite in the metal /glass contact region ($T^* \sim (800...1200)$ K), T is the room temperature; k is the ratio between Young's moduli of the

glass and the metal; ν is the Poisson ratio. Let us consider the case where all the Poisson ratios are $\nu = 1/3$ in order to obtain

$$P = \varepsilon E_1 \frac{kx}{(k/3+1)x+4/3}, \quad (4)$$

$$\sigma_z = P \frac{(k+1)x+2}{kx+1}, \quad (5)$$

With additional longitudinal strain, which occurs when the microwire is embedded in a solid matrix that itself deforms under external influence, the following term is added to the expression for the residual axial tension:

$$\sigma_{ez} = \frac{P_o}{S_m(kx+1)}, \quad (6)$$

where P_o is the force applied to the composite; $S_m = \pi(R_m)^2$ is the microwire cross-sectional area.

The theory of NFMR is presented in Refs. [6-8]. The NFMR frequency can be written as

$$\omega(GHz) \approx \omega_o \left(\frac{0.4x}{0.4x+1} + \frac{\sigma_{ez}}{\sigma_o} \right)^{1/2}, \quad (7)$$

$$\omega_o(GHz) \approx 1,5(0.6\lambda)^{1/2}$$

where

Conclusion

We have presented simple analytical expressions for the residual and external stresses in the metallic kernel of the microwire, which clearly show their dependence on the ratio of the external radius of the microwire to the radius of the metal kernel and on the ratio of Young's modules of glass and metal. The NFMR phenomenon observed in glass-coated magnetic microwires opens up the possibility of developing new materials with a wide range of properties [19-21]. An important feature of cast microwires with an amorphous magnetic core is the dependence of the NFMR frequency from the deformation (see Equations (7)).

Therefore, this effect can be used for contactless diagnostics of deformations in distant objects (including critical infrastructures) reinforced by cast magnetic microwires with the stress effect. These objects are periodically scanned with floating-frequency radar to determine the deviation of the initial NFMR frequency due to potentially dangerous deformations of the monitored object.

Another principle of detecting mechanical strain is examined in Ref. [21]. This principle is based on the giant magnetoimpedance (GMI) effect. The GMI effect [17,18] demands external magnetization of the sample which is not required in the NFMR method [6-8].

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Conflict of Interest

No conflict of interest.

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