PROPAGATION OF A SINGLE DOMAIN WALL IN AMORPHOUS WIRE

*Jozef KRAVČÁK
*Department of Physics, Faculty of Electrical Engineering and Informatics,
Technical University of Košice, Park Komenského 2, 042 00 Košice, tel. 055/602 3206, E-mail: kravcak@tuke.sk

SUMMARY

The domain wall dynamics during magnetization reversal of a magnetostrictive FeSiB amorphous wire is described by means of the core-shell model assuming residual radial tensile stresses in the as-cast state. The appearance of a square-shaped low field hysteresis loop is ascribed to the propagation of a single magnetic domain wall along an internal core of the wire with axial magnetization. A modified Sixtus-Tonks experiment [1] for the FeSiB amorphous wire has been performed to investigate a shape of the propagating domain wall and its velocity.

Keywords: amorphous ferromagnetic wire, Barkhausen effect, domain wall dynamics.

1. INTRODUCTION

In amorphous wires of various compositions prepared by rapid quenching of the melt in rotating water, a vertical step in the low field hysteresis loop is observed in the as-cast state, when magnetostriction, coupled with frozen-in internal stresses, is large enough to produce so called core-shell magnetic domain structure. The low field hysteresis loop displays then so called magnetic bistable behaviour, since axially magnetized core can switch from one stable state to the other at critical magnetic field H_o. Obviously, magnetization reversal starts by depinning of a domain wall from the closure structure at an end of the wire, Fig. 2a. The propagation of this domain wall can be observed by arranging two short pick-up coils along the wire. The induced voltage impulses, their shape and time difference, can be used to describe the shape and size of the domain wall and its velocity.

2. SAMPLE AND EXPERIMENT

In the experiment the amorphous wire produced by the technique of quenching in rotating water was used in as-cast state with a nominal composition $Fe_{77.5}Si_{7.5}B_{15}$, a positive saturation magnetostriction ($\lambda_s = 35 \times 10^{-6}$) of a diameter $2r_0 = 125\ \mu m$ and a length of 30 cm. The Sixtus-Tonks technique [1] with some modification was used to study the domain wall dynamics during its propagation. The wire was placed into a 41 cm long magnetizing coil C_m and surrounded by two short 5 mm pick-up coils, C_1 and C_2. The schematic view of experimental arrangement is shown in Fig. 1. The Sixtus-Tonks experiment was performed, after slow magnetization of the wire in one direction, and switching of the external field to a certain value H_m. Propagation of the reverse domain wall through pick-up coils C_1 and C_2 induced voltage impulses, which were recorded by digital oscilloscope.

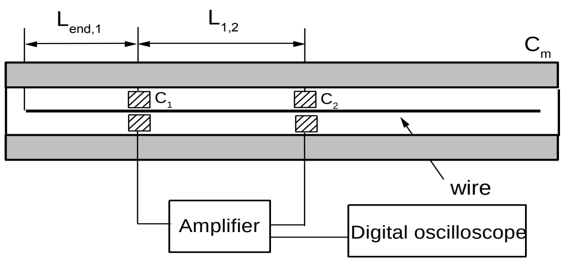

Fig. 1 Schematic diagram of the arrangement of Sixtus-Tonks experiment. C_m is 41 cm long magnetizing coil, C_1, C_2 are 5 mm long pick-up coils. Induced signal in pick-up coils is 10 000 times magnified.

3. EDDY CURRENT MODELS

3.1. Tubular Wall Model

A tubular wall model was originally proposed by Williams, Shockley, and Kittel [2] to explain the eddy current damping in the wire and with some modifications is applicable in the amorphous wire, as well [3]. In case of a conical reverse domain wall, Fig. 2a, with propagation the wall radius r_w on each cross section of the wire increases from 0 to r_c, where r_c is the radius of axially magnetized core, Fig. 2b. If the wall length L_w is much greater than r_c, which is again much greater than the wall thickness, then this model can be used for each small Δz segment of the wall with high accuracy. This model assumes that in a uniform applied field H_m, the magnetization reversal from $-M_s$ to M_s, the saturation magnetization along the z axis, is through an increase in radius r_w of 180° cylindrical wall formation from 0 to r_c.

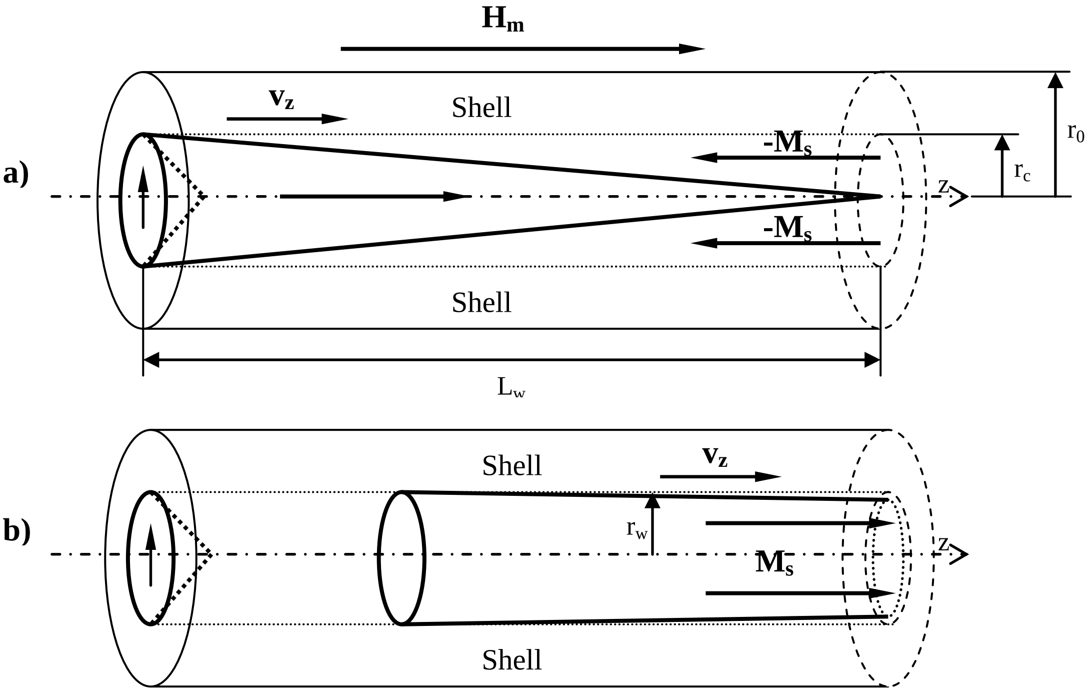

Fig. 2 Domain structure scheme for $Fe_{77.5}Si_{7.5}B_{15}$ wire showing closure reverse spike domain in the core at the end of the wire: a) at remnant state, b) after depinning at $H_m > H_0$.

From Faraday's law and Ohm's law, for a sample of a resistivity ρ, using Ampere's theorem, the eddy-current field H_z at the wall can be derived

$$H_z(r_w) = \frac{2\mu_0 M_s r_w}{\rho} ln \frac{r_0}{r_w} \frac{dr_w}{dt} \tag{1}$$

And the applied external field should be

$$H_m = H_0(r_w) - H_z(r_w) \tag{2}$$

where $H_0(r_w)$ is the hysteretic pinning (critical) field for the wall. Suppose that $H_0(r_w)$ is a constant (in real wires it cannot be constant owing to their r_w dependent stress and wall area), so that $H_z(r_w)$ is also constant.

Suppose that after depinning, the reverse domain wall has a fixed geometry and propagates with a constant axial velocity v_z , Fig. 2b. The wall shape can be derived from (1) and expressed as its z coordinate, z_w, versus its r coordinate, r_w :

$$z_w(r_w) = \int_{r_w}^{r_c} H_z(r) \frac{dz}{dr} dr = \frac{\mu_0 M_s v_z}{H_z(r_w)\rho}\left[r_w^2\left(ln\frac{r_0}{r_w} + \frac{1}{2}\right) - r_c^2\left(ln\frac{r_0}{r_c} + \frac{1}{2}\right)\right] \tag{3}$$

For the induced voltage impulse waveform then holds:

$$\frac{dM(r_w)}{dt} = \frac{2H_z(r_w)\rho}{\mu_0 r_c^2}\left(ln\frac{r_c}{r_w}\right)^{-1} \tag{4}$$

Using (2) and (3) the propagation velocity of the conical reverse domain wall is derived :

$$v_z = \frac{L_w \rho}{\mu_0 M_s r_c^2}\left(ln\frac{r_c}{r_w} + \frac{1}{2}\right)^{-1}\left(H_m - H_0\right) \tag{5}$$

3.2. Planar Wall Displacing Model

Another eddy-current model which may be used is the planar wall displacing model [3]. In this case, a planar wall cuts the wire making a small angle with the axis, so that the wall propagation can be in each small Δz segment approximated as a 180^o wall parallel to the axis and displacing from one side to its opposite, Fig. 3. Analytical derivation for a cylindrical sample is difficult, but existing result for a rectangular bar derived by Williams, Shockley, and Kittel [2] can be in first approximation used. Assuming the wall position to be x_w , Fig. 3, which changes from $-r_c$ to r_c during magnetic reversal as :

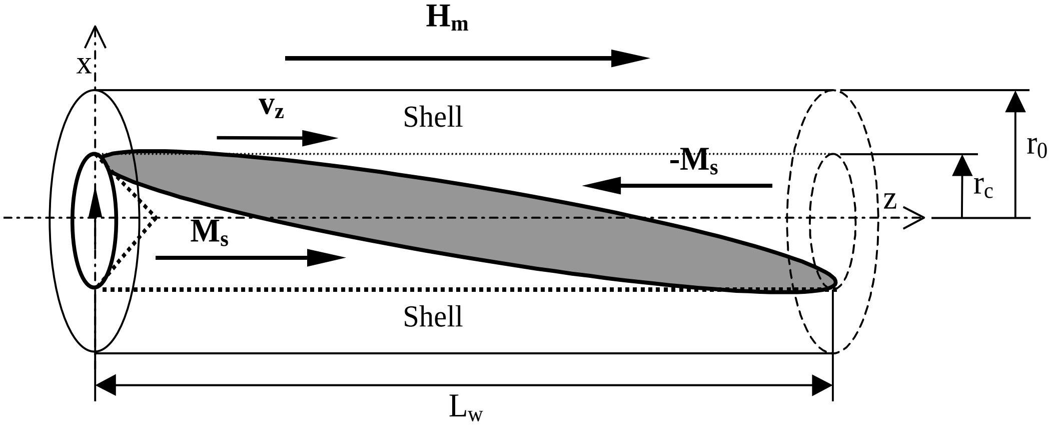

Fig. 3 Domain structure scheme for $Fe_{77.5}Si_{7.5}B_{15}$ wire showing quasi planar reverse domain wall in the core of the wire after depinning at $H_m > H_0$.

$$x_w(t) = r_c(1 - 2v_z t / L_w) \tag{6}$$

the induced voltage impulse waveform is then given by :

$$\frac{dM(t)}{dt} = \frac{8v_z M_r}{\pi L_w}\sqrt{1-\left(1-\frac{2v_z}{L_w}t\right)^2} \tag{7}$$

The expression for propagation velocity of the quasi-planar reverse domain wall can be derived using (6) and (7) :

$$v_z = \frac{L_w \rho}{\mu_0 M_s r_c^2}\left(ln\frac{r_0}{r_w}+\frac{8}{\pi^2}\right)^{-1}\left(H_m - H_0\right) \tag{8}$$

4. RESULTS AND DISCUSSION

The results obtained in the modified Sixtus-Tonks experiment made possible to calculate the average value of axial velocity of the propagating wall $v_z = L_{1,2} / \Delta t$, where $\Delta t = t_2 - t_1$ is the time interval between the induced signals and $L_{1,2}$ is the distance between the pick-up coils C_1, C_2. The average value of velocity v_z linearly increases with the external field H_m, as it is expected by theoretical expression $v_z = S\,(H_m - H_0)$ [2], where S is a wall mobility. The fitting of experimental data gave the value of $S = 109.2\ m^2/A$, and the critical magnetic field $H_0 = 15.8\ A/m$, Fig. 5. The estimate of the diameter of the axially magnetized core was made and gave the value of $2r_c = 70\ \mu m$ [4].

Fig. 4 presents a change of characteristic form of induced impulses at different external fields H_m. For interpretation of the voltage impulses waveform induced by the propagating wall, the tubular-wall eddy-current model, eq. (5), and the planar-wall eddy-current model, eq. (7), are used. A comparision between the experimental data, which are obtained in this work and reported in literature [3], and the model expectations yield the conclusion that propagating wall is basicaly conical at lower external fields, when depinning of the domain wall occurs. Nevertheless at the higher external fields H_m > 25 A/m the shape of domain wall changes to quasi-planar, Fig. 3. This is evident from induced voltage impulses at short time intervals, Fig. 4.

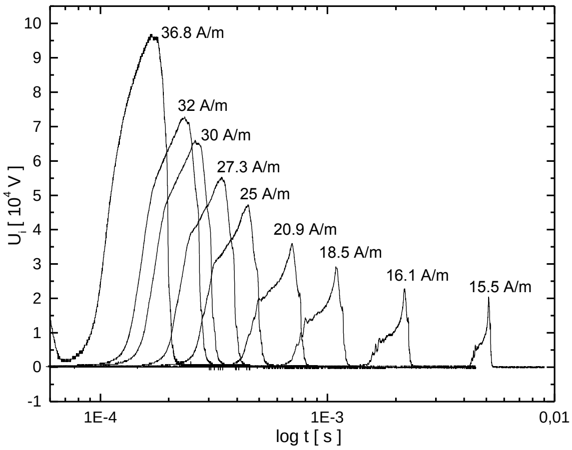

Fig. 4 Induced impulses during the propagation of the reverse domain wall at displayed external driving field H_m. The first type of impulses recorded at lower fields (H_m = 15.5 A/m, ..., 25 A/m) corresponds to the propagation of the conical reverse domain wall. The second type of impulses recorded at higher fields (H_m > 25 A/m) displays a shape transformation of the propagating reverse domain wall to a quasi-planar wall (see Fig. 2, 3).

CONCLUSION

The modified Sixtus-Tonks experiment with the amorphous $Fe_{77.5}Si_{7.5}B_{15}$ wire placed in a uniform external magnetic field was performed. The magnetic reversal started by depinning of the conical wall from the closure structure at an end of the wire. The domain wall shape transformation occured at the external field $H_m > 25$ A/m, when the induced signal waveform corresponds to the propagation of the quasi-planar reversal domain wall, Fig. 4. A linear characteristic of the wall velocity v_z versus external field H_m , was observed, Fig. 5.

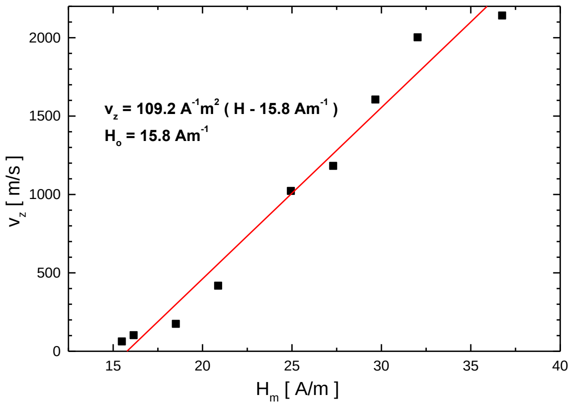

Fig. 5 The measured dependence of the axial velocity v_z of the propagating reverse domain wall on the intensity of the external driving field H_m fitted by the theoretical straight line $v_z = S (H_m - H_0)$.

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BIOGRAPHY

J. Kravčák, biography not available at time of publication.