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BLOCH WALL DYNAMIC INSTABILITY AND WALL MULTIPLICATION IN AMORPHOUS RIBBONS OF METGLAS 2605 SC

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Abstract. — The theoretical results concerning the calculation of the critical speed at which a Bloch wall becomes unstable under the action of a driving field and the eddy currents field are compared with the experimental ones obtained on a strip of Metglas 2605 SC characterized by a well defined structure of antiparallel domains. A good agreement is obtained by assuming a value of \( 0.97 \times 10^{-9} \text{ J/m}^2 \) for the wall surface energy \( \gamma_0 \). This method, which is based on direct experimental results, seems to be a simple and reliable way to obtain rather accurate values of \( \gamma_0 \) in amorphous alloys.

Introduction

In ferromagnetic materials characterized by a rather regular structure of antiparallel domains, wall multiplication effects take place when they are magnetized at a sufficiently high frequency. Instabilities for a Bloch wall moving above a critical speed have been predicted by Bishop [1] on the basis of his theory of bowing. In the present paper it is shown by comparing experimental and theoretical results, that, in the case of a well defined antiparallel domain structure, wall multiplication takes place when the walls reach a critical speed which can be exactly calculated when the resistivity \( \rho \), the saturation magnetic polarization \( J_0 \), the wall surface energy \( \gamma_0 \) and the thickness \( d \) of the specimen are known. Inversely, these results show that it is possible, from permeability measurements on specimens characterized by a structure of sufficiently spaced antiparallel domains, to make a rather accurate measurement of \( \gamma_0 \), a quantity which is by no means easily measured.

Experimental results

Experiments have been done on strips of an amorphous ribbon, Metglas 2605 SC, having a width of 5 mm, a thickness of 45 \( \mu \text{m} \), and a length of 100 mm, characterized under a tension of 300 MPa by a few antiparallel domains.

The demagnetizing factor \( N \) was obtained from the measurement of the magnetic polarization \( J \) vs. the applied field \( H_\text{a} \) at a low magnetizing frequency. From the slope of the curve, which was mostly a straight line, except on its initial and final part, a value of \( N \) of 54.3 Am\(^{-1}\) T\(^{-1}\) was obtained. The true magnetic field acting on a wall was thus calculated through the equation \( H_\text{e} = H_\text{a} - NJ \).

Measurements of \( J \) vs. \( H_0 \) applying sinusoidal fields of different frequency and amplitude are reported in figure 1. The reaching of a critical speed giving rise to wall multiplication is evidenced by a knee in these curves. It can be seen that for all the curves the knee occurs at about the same critical field \( H_c \) of \( 80 \text{ Am}^{-1} \). The small increase in \( H_c \) when the magnetizing frequency increases is due to the fact that the oscillation amplitude decreases. Because the proposed theory is developed under the assumption of a constant speed of the Bloch wall, theoretical results about \( H_c \) should better compare with the experimental ones obtained at lower magnetizing frequencies and thus at larger oscillation amplitudes (about \( 10^{-4} \text{ m} \) at 30 kHz as compared with a wall bowing of only \( 1.5 \times 10^{-5} \text{ m} \)).

Discussion

In the absence of anisotropy energy, the differential equation describing the wall bowing in stationary conditions within a lamination can be derived from the variational principle [2]

\[
\delta \int_0^d \left[ \gamma_0 \sqrt{1 + y'(x)^2} + g(x) y(x) \right] dx = 0 \tag{1}
\]

where \( y(x) \) gives the wall profile along the \( x \) axis.

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perpendicular to the lamination surface. The Euler-
Lagrange equation derived from equation (1) writes:
\[
\frac{d}{dx} \frac{\partial R}{\partial y'} = \frac{\partial R}{\partial y} = 0 \tag{2}
\]
with
\[
R \left( y, y' \right) = \gamma_0 \sqrt{1 + y'^2} + g(x) y \tag{3}
\]
In these equations \( g(x) \) represents the pressure of the applied and eddy currents fields acting on the wall, while \( \gamma_0 \) is the surface energy. Using the expression of the eddy currents field for a wall moving at a constant speed \( v \) given in [3], we get
\[
R \left( y, y' \right) = \gamma_0 \sqrt{1 + y'^2} + \frac{1}{x} \times \left[ \left( 8d^2 J_s^2 v \right) B(x) / \rho - 2J_s H_0 \right] \tag{4}
\]
where \( d \) is the thickness, \( J_s \) the saturation magnetic polarization and \( \rho \) the resistivity of the lamination, \( H_0 \) is the magnetic field acting on the wall and \( B(x) \) is given by:
\[
B(x) = \left( 1 / d \right) \sum_{n=1}^{\infty} \frac{1}{n \pi x} \times \cos \left[ \frac{n \pi}{d} \left( \frac{d}{2} - x \right) \right] \tag{5}
\]
\[
\int_0^{d/2} \cos \left( \frac{h n \pi}{d} \right) \times \exp \left\{ - \left[ y \left( \frac{d}{2} - x \right) - y(h) \right] \pi n \right\} \frac{d}{d} \tag{6}
\]
the sum \( \Sigma' \) being over the odd integer values of \( n \).
From equations (2) and (4) we finally obtain
\[
y'' = \left[ 8d J_s v B(x) / \left( \rho \gamma_0 \right) - 2J_s H_0 / \gamma_0 \right] / \left[ \left( 1 + y'^2 \right)^{-1/2} \times \left( 1 + y'^2 \right)^{-1} \left( 1 + y'^2 \right)^{-2} \right] \tag{6}
\]
In order to solve numerically equation (6) a fourth order Runge-Kutta method has been used. The quantity \( B(x) \) is calculated in a self-consistent way using an iterative procedure.
Actually, assuming as a first step that the eddy currents field is generated by the wall as if it were flat, the exponential term within the integral becomes equal to 1 and the dependence of \( B(x) \) on the unknown function \( y(x) \) vanishes. As a second step the wall bowing is introduced, a new calculation of \( B(x) \) is performed, and so on.
If calculations of the wall bowing are made introducing increasing values of the applied field, a critical value is eventually reached, above which an analytical solution cannot be found any longer. This happens when the wall curvature cannot any more compensate the local difference between the pressures due to the driving field and the eddy currents field and the wall blows. This critical situation is shown in figure 2, where also the eddy currents field \( H_d \) and its average value, which is equal in modulus to the driving field \( H_0 = H_c \), are reported.

Because \( J_s \) and \( \rho \) are known quantities, the only adjustable parameter is the surface wall energy \( \gamma_0 \). By assuming, from the results of figure 1, a critical field between 75 – 85 A/m a value of \( \gamma_0 \) between 0.97 x 10^{-3} and 1.1 x 10^{-2} J/m^2 is derived. The corresponding critical velocities are between 8.6 and 9.7 m/s and compare well with those obtained from the values of \( J \) at the critical field in figure 1 if 4 walls moving at the same speed are assumed. It should be noted however that \( H_c \) is the only experimental quantity needed to obtain \( \gamma_0 \).

Conclusions

In the present paper it has been shown that in specimen characterized by a well defined structure of antiparallel domains, walls multiplication takes place when the field acting on a wall reaches a critical value which can be calculated once the resistivity, the saturation magnetization, the wall surface energy and the lamination thickness are known. Experiments done on amorphous ribbons yield a value of \( \gamma_0 \) which is about 40 % higher that the one estimated for a Fe_{80}B_{20} amorphous alloy by theoretical considerations in another paper [4].

The present method, which is based on direct experimental results, seems a reliable way to obtain correct values of \( \gamma_0 \) on amorphous alloys.