1. Introduction

The eddy currents distribution for a single plane domain wall moving in a rectangular ferromagnetic bar was studied by Williams et al. [1]. Based on this work the extended model was developed containing a central rectangular ferromagnetic layer — core — and two conducting non-ferromagnetic layers — shell (see Fig. 1) [2]. The movement of a single domain wall was also studied by Colaiori et al. [3] by means of diffusion equation for eddy currents. The following calculations are done on the assumption that electric and magnetic fields are propagated instantaneously (displacement current is neglected). The current density $j$ is the solution of the differential equations: $\nabla^2 j = 0$, $\text{rot} j = 0$, $\text{div} j = 0$.

Using the boundary condition: $j_n = 0$, normal component of $j$ is equal to zero on all outer sample surfaces, gives

$$j_x (x, y) = \sum_{n=1}^{\infty} D_n \sinh \left( \frac{n\pi}{h} (L_{1,2} - x) \right) \times \cos \left( \frac{n\pi}{h} \left( y - \frac{h}{2} \right) \right),$$

$$j_y (x, y) = \sum_{n=1}^{\infty} D_n \cosh \left( \frac{n\pi}{h} (L_{1,2} - x) \right) \times \sin \left( \frac{n\pi}{h} \left( y - \frac{h}{2} \right) \right),$$

where $L_1$ is for interval $x < 0$ and $L_2$ is for interval $x > 0$. Additional boundary condition should be applied within the sample at the domain wall position ($x = 0$): $\text{rot} j = -\gamma \mu_0 \frac{dM}{dt}$, where $dM/dt$ is a rate of magnetization change, $\gamma$ is the sample conductivity and $\mu_0$ is magnetic permeability and it yields the coefficients

$$D_n = \frac{4\gamma \mu_0 \mu_5 v \sin(n\pi/2) \sin(n\pi d/(2h))}{n\pi \cosh(n\pi L_{1,2}/h)},$$

for $n = 1, 2, 3, \ldots$, where $v$ is domain wall velocity and $d$ is domain wall thickness.

Fig. 1. Magnetic reversal (domain wall movement) in FML. The rectangle width is $L_1 + L_2 = 2$.

Thus the sample width is $L_1 + L_2$. The FML thickness is denoted by $d$.

Generally, the theory of eddy currents is based on a diffusion equation solution [3]. The following calculations are done on the assumption that electric and magnetic fields are propagated instantaneously (displacement current is neglected). The current density $j$ is the solution of the differential equations: $\nabla^2 j = 0$, $\text{rot} j = 0$, $\text{div} j = 0$.

2. Model description and eddy currents calculation

We introduce a rectangular sample with dimensions $x \in [-L_1, L_2]$, $y \in [-h/2, h/2]$, and infinite in the $z$ direction. The sample contains three conducting layers, two outer layers are not ferromagnetic (NFL) and the central one is ferromagnetic (FML) with uniform antiparallel magnetization with respect to $z$ direction. If an external magnetic field of intensity $H$ is applied in $z$ direction, magnetic reversal of FML occurs by the propagation of a single rigid plane $180^\circ$ domain wall (DW) from the left to the right sample boundary as displayed in Fig. 1. The origin of the coordinate system is placed in a centre of the moving DW ($x = 0$). It should be pointed out that $L_1$ and $L_2$ are variable distances of the DW from left and right sample boundary, respectively.

### References

1. Williams et al. [1]
2. Colaiori et al. [3]
3. Diffusion equation solution
4. Magnetic permeability and anisotropy

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the + sign is valid for \( j_y(x, y) \) with \( L_1 \) in interval \( x \leq 0 \) only.

3. Results and discussion

From Eqs. (1) and (2) we have numerically calculated a non-homogeneous magnetic field intensity \( H_z(x, 0) \) generated by eddy currents along the \( x \) axis \( (y = 0) \) using the Biot–Savart law [5], see Fig. 2. The eddy currents field intensity at the DW position \( (x = L_2) \), which will move in opposite direction. Neglecting other interactions of DW (e.g. DW pinning, tilting and the Hall effect) a linear dependence of the DW velocity \( v \) on driving field intensity \( H \) was derived from (1) and (2):

\[
 v = S H \quad [2] ,
\]

where \( S \) is the DW mobility

\[
 S = \left( \pi^3 d / \{ 4 \hbar^2 \gamma \mu_0 M_S \sum_{n=1}^{\infty} n^{-3} \left( \tanh(n \pi L_1 / h) + \tanh(n \pi L_2 / h) \right) \sin^2(\pi n / 2) \sin^2(\pi d / (2h)) \} \right). \quad (3)
\]

The calculated dependences of the DW mobility on the DW position (distance \( L_1 \)) and on the ratio \( d/h \) (the FML thickness to overall sample thickness \( h \)) are displayed as inset in Fig. 3. We can see the maximum DW mobility on both sides of the rectangle and the minimum DW mobility \( S_m \) at the center of the rectangle. The mobility \( S_m \) rapidly decreases with the ratio \( d/h \) in Fig. 3. We observe at the ratio \( (d/h)_{\text{min}} = 0.77 \) the absolute minimum DW mobility.

4. Conclusions

The presented theoretical model deals with magnetic reversal of the rectangular sample consisting of one central ferromagnetic layer and two outer conductive non-ferromagnetic layers. The magnetic reversal in external magnetic field of low intensity is connected with propagation of one single plane domain wall through the ferromagnetic layer. The proposed geometry of the sample allows us to calculate exactly the eddy currents distribution and to determine the generated eddy currents field in the sample as well. We have shown the theoretical possibility of the nucleation of new DW (moving with a negative velocity) induced by the eddy currents field. This effect can manifest itself in a sudden increase of the DW velocity which could be observable in the Sixtus–Tomkins experiment. We have also shown that conductivity and thickness of non-ferromagnetic layers with respect to the thickness of a ferromagnetic layer play a very important role in the DW mobility and the ratio \( d/h = 0.77 \) gives us the absolute minimum DW mobility.

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References