Domain structure of a ferromagnet in a rapidly oscillating magnetic field

A. K. Zvezdin and V. G. Red'ko

(Submitted February 23, 1975)
ZhETF Pis. Red. **21**, No. 7, 445–447 (April 5, 1975)

It is shown that the effective energy of the domain walls changes in a high-frequency magnetic field. The possible domain-structure rearrangement due to the effect is considered.

In this paper we study the behavior of domain walls and domains in a magnetic field oscillating with time with a frequency much higher than the ferromagnetic-resonance frequency. We assume that the high-frequency field **h** causes the magnetization to execute small oscillations **m** relative to the smoothly varying value $\mathbf{M}_0$. In this formulation, the situation recalls a problem considered by P.L. Kapitza, that of the motion of a particle acted upon simultaneously by a constant field and a rapidly alternating force.[1] 1)

1. The equations of motion of the magnetization in spherical coordinates are

$$\dot{\theta} = -\frac{\gamma}{M\sin\theta}\frac{\delta E}{\delta\phi} - \alpha\dot{\phi}\sin\theta, \qquad \dot{\phi}\sin\theta = \frac{\gamma}{M}\frac{\delta E}{\delta\theta} + \alpha\dot{\theta}, \tag{1}$$

where the angles θ and ϕ determine the orientation of the magnetization **M**, E is the energy density, γ is the gyromagnetic ratio, α is the damping parameter, $E = E_0 + E_h$, and $E_h = -\mathbf{M}\cdot\mathbf{h}$ is the energy in the field **h**. We assume that $\theta = \overline{\theta} + \theta_1$ and $\phi = \overline{\phi} + \phi_1$, where $\overline{\theta}$ and $\overline{\phi}$ are the angles averaged over the oscillations, while θ_1 and ϕ_1 are small ($\gamma h \ll \omega$) rapidly oscillating quantities. We use the following calculation procedure[1,2]: a) we expand Eqs. (1) in powers of θ_1 and θ_1, confining ourselves to a quadratic or linear approximation; b) we separate the smoothly-varying and rapidly-oscillating quantities in the obtained expressions; c) from the equations for the oscillating variables we obtain θ_1 and ϕ_1, substitute these values in the formulas for the smooth quantities, and thus obtain equations for $\overline{\theta}$ and $\overline{\phi}$.

2. Let us investigate the effect of a linearly polarized field $\mathbf{h} = \mathbf{h}_0\cos\omega t$ on the domain-wall structure in a uniaxial ferromagnet. Neglecting damping and confining ourselves in (1) to the approximation quadratic in θ_1 and ϕ_1, we obtain equations for $\overline{\theta}$ and $\overline{\phi}$:

$$\overline{\frac{\delta E_0}{\delta\theta}} = 0, \qquad \overline{\frac{1}{\sin\theta}\frac{\delta E_0}{\delta\phi}} = 0. \tag{2}$$

The energy density E_0 is given by

$$E_0 = A\left[\sin^2\theta\left(\frac{d\phi}{dx}\right)^2 + \left(\frac{d\theta}{dx}\right)^2\right] + K\sin^2\theta + 2\pi M^2\sin^2\theta\cos^2\phi. \tag{3}$$

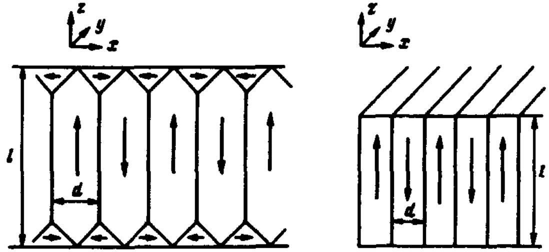
Here A is the exchange constant, K is the anisotropy constant, the z axis is directed along the easy axis, and the x axis is perpendicular to the plane of the wall. Assuming for the Bloch and Neel walls $\overline{\phi} = \pi/2$ and $\overline{\phi} = 0$, we find that at the investigated field orientations (see the table) the equation for θ reduces to the usual form, but with an effective anisotropy constant K_{eff} (compare with U_{eff} in[1]), namely $K_{eff}\sin\overline{\theta}\cos\overline{\theta} = A(d^2\theta/dx^2)$. The values of K_{eff} are listed in the table. The domain-wall energy $\sigma_w = \int(\overline{E} - \overline{E}_d)\,dx$, where $\overline{E}_d$ is the value of $\overline{E}$ inside the domains, is given by $\sigma_w = 4(AK_{eff})^{1/2}$. Physically, the change of σ_w in the oscillating field means that

Field direction		Bloch wall	Neel wall
$\mathbf{h} \parallel x$	K_{eff}	$K(1-\epsilon^2)$	$K\left(1-\frac{1}{2}\epsilon^2\right)+2\pi M^2$
	$\bar{E}_d$	$\frac{1}{2}K\epsilon^2$	
$\mathbf{h} \parallel y$	K_{eff}	$K-\frac{1}{2}(K+2\pi M^2)\epsilon^2$	$(K+2\pi M^2)(1-\epsilon^2)$
	$\bar{E}_d$	$\frac{1}{2}(K+2\pi M^2)\epsilon^2$	
$\mathbf{h} \parallel z$	K_{eff}	$K+\pi M^2\epsilon^2$	$K-\pi M^2\epsilon^2+2\pi M^2$
	$\bar{E}_d$	0	

when the magnetization precesses in the field $\mathbf{h}$ a change takes place in the average anisotropy energy and the demagnetization in the domain walls.

3. Let us examine the change of a layered domain structure (see the figure) in a field $\mathbf{h}(t)$. Let $\mathbf{h} \parallel z$; we determine the period of a structure with closing domains (Fig. 8). The energy per unit volume of the sample ($l \gg d$) is $E_t=\sigma_w d^{-1}+(1/2)Kdl^{-1}$. Assuming that the equilibrium domain dimensions are determined by the usual condition that the average energy be minimal, we obtain $d=d_0(K_{eff}/K)^{1/4}$, where d_0 is the width of the domains at $\mathbf{h}=0$. Assuming $\pi M^2/K \sim 10$, $h_0 \sim 10$ Oe, and $\omega \sim 10^9$ sec^{-1}, we obtain $d/d_0 \approx 1.1$. For the structure shown at Fig. b we can show analogously that at $K > 2\pi M^2$ and $\bar{\phi}=\pi/2$ the value of E_t is smaller in a field $\mathbf{h} \parallel x$ than in a field $\mathbf{h} \parallel y$, i.e., the domain walls tend to turn perpendicular to the field $\mathbf{h}$.

4. An interesting situation arises at arbitrary polarization of the field, $\mathbf{h}=\mathbf{h}_0\exp(i\omega t)+\mathbf{h}_0^*\exp(-i\omega t)$. Following the procedure described above, we can show that, in the approximation linear in θ_1 and ϕ_1, the equations of motion for $\mathbf{M}_0$ acquire an additional effective field



a b

$$\mathbf{f}=-\frac{\gamma}{i\omega(1+\alpha^2)}\left\{[\mathbf{h}_0\times\mathbf{h}_0^*]+\frac{\alpha}{M}[\mathbf{M}_0\times[\mathbf{h}_0\times\mathbf{h}_0^*]]\right\}. \quad (4)$$

If the field $\mathbf{h}$ is linearly polarized, then $\mathbf{f}=0$. If $\mathbf{h}$ is circularly polarized in the xy plane, then $\mathbf{f}$ has in the case of small damping only a z component, $f_z=(1/2)\gamma h_0^2/\omega$.[2)] In such a field, an additional pressure is exerted on the domain walls by the difference between averaged energy densities in the domains with opposite methodizations.

The considered effects were obtained under the condition $\omega > \omega_{res}$, but since they are determined by the amplitude of the magnetization oscillations we can expect them to increase and tend to ω_{res}.

The authors are grateful to V.M. Eleonskiĭ for useful discussions.

[1)]The behavior of ferromagnets without a domain structure in a rapidly oscillating field was investigated in[2].
[2)]A similar result was obtained from other considerations.[3]

[1]L. D. Landau and E. M. Lifshiftz, Mekhanika (Mechanics), Moscow (1965), Sec. 30 [Addison-Wesley, 1971)].
[2]A. I. Akhiezer and S. V. Peletminskiĭ, Fiz. Tverd. Tela 10, 3301 (1968) [Sov. Phys.-Solid State 10, 2609 (1969)].
[3]E. Schlöman and J. D. Milne, Digests of the Intermag. Conference (1974), Toronto, 24/5.