

Magnetic inhomogeneities of soliton and breather type in magnetics with local nonhomogeneities of anisotropy

E.G.Ekomasov, Sh.A.Azamatov, R.R.Murtazin

Bashkir State University, 34, Frunze St., 450074 Ufa, Russia

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Using numerical methods, the peculiarities of domain wall transition through the two-dimensional region of magnetic anisotropy constant inhomogeneity has been considered. The origination and evolution of pulson type magnetic inhomogeneities localized in this region have been studied.

С помощью численных методов рассматриваются особенности прохождения доменной границы через двумерную область неоднородности константы магнитной анизотропии. Исследовано зарождение и эволюция локализованной магнитной неоднородности типа пульсона в этой области.

In various physical applications, much attention is given to the dissipation nature of mobile excitation on local heterogeneities of the material parameters, including solitons and kinks [1]. Of a special interest is the case when the size of a magnetic inhomogeneity and the size describing the inhomogeneity of the material parameters are of the same order. Then the form of the magnetic inhomogeneity should undergo strong changes at transit through an inhomogeneous area. In one-dimensional case, the problem, under certain conditions, is reduced to the analysis of a modified sine-Gordon equation (MSGE) with variable factors [2]. To date, the perturbation theory for the equation of that type has been developed that permits in principle to find both motion of a kink mass center and the change of its form and emission of small oscillations [3]. However, for magnetics, it was utilized only to find the motion law of a domain wall (DW) mass center, and in specific case of an inhomogeneity of the material parameters [2]. The influence of large perturbations on the MSGE solution in general case can be studied only using numerical methods. The experimental works [4, 5] have also show, that the defects in rare earth orthoferrites (REO) can result in an inhomogeneity of the magnetic anisotropy constant (MACI). The process of nucleation and evolution of magnetic inhomogeneities for the case of 1D inhomogeneity of the magnetic anisotropy constant was studied using numerical methods [6]. In experimental work [7], the modification of the DW structure at the transition through a defect region in a thin plate of yttrium orthoferrite was investigated. In this paper, the DW transition through a 2D MACI region is studied, excitation and emission of nonlinear waves especially for the large values of the orthoferrite inhomogeneity parameters.

The state of an infinite REO crystal in twosublattical model can be described by two magnetization vectors of the sublattices of the same module, $|\mathbf{M}_1| = |\mathbf{M}_2| = M_0$. These vectors can be used for the introduction of ferro- and antiferromagnetics vectors $\mathbf{m} = (\mathbf{M}_1 + \mathbf{M}_2)/2M_0$, $\mathbf{l} = (\mathbf{M}_1 - \mathbf{M}_1)/2M_0$ which are connected by the correlations $m^2 + \ell^2 = 1$, $\mathbf{ml} = 0$. Let the coordinate axes *x*, *y* and *z* be di-

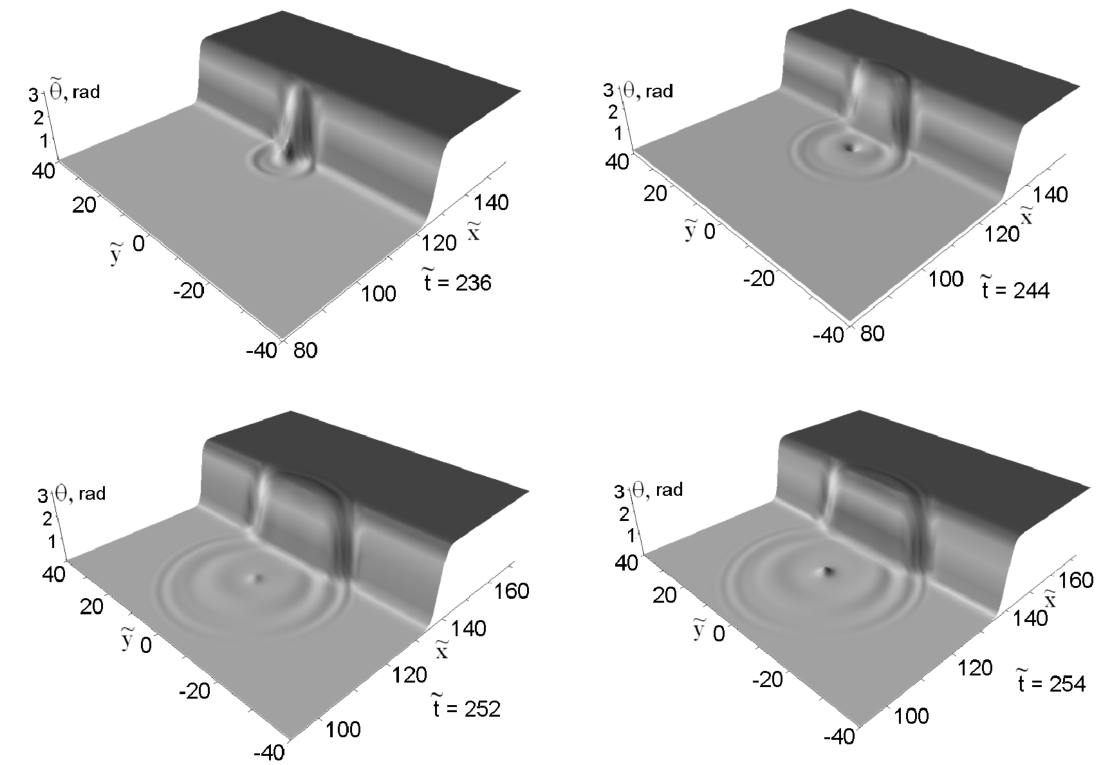

Fig. 1. Domain wall structure changes for case $\tilde{W}_x = 2$, $\tilde{W}_y = 2$, $\tilde{K} = -1.5$, $\tilde{v}_{limit} = 0.6$, $h = 0.022$.

rected along crystallographic axes $\mathbf{a}$, $\mathbf{b}$ and $\mathbf{c}$, respectively. Let a single Neel DW be considered in a high-temperature magnetic phase $G_x F_z$ with its plane being perpendicular to axis x. Supposing that $\mathbf{m} << \mathbf{l}$ in spherical coordination system, the vector $\mathbf{l}$ can be presented as $\mathbf{l}(\cos\theta, \sin\theta\sin\varphi, \sin\theta\cos\varphi)$. No exit of $\mathbf{l}$ and $\mathbf{m}$ from the plane of turning in static DW $(\varphi = 0)$ is assumed in dynamics. Let new dimensionless variables: $\tilde{x} = x/\delta_0$, $\tilde{y} = y/\delta_0$, $\tilde{t} = t/(\delta_0/c)$, $\delta_0 = \sqrt{A/K^0_{0A}}$, $c = \gamma\sqrt{aA}/2M_0$ be introduced, where A and a being constants of homogeneous and inhomogeneous exchange; K^0_{ac}, effective constant of anisotropy in ac plane in homogeneous crystal; γ – gyromagnetic ratio. Then the motion equation for $\theta(x,y,t)$ can be written in the following form:

$$\frac{\partial^2\theta}{\partial\tilde{x}^2} + \frac{\partial^2\theta}{\partial\tilde{y}^2} - \ddot{\theta} - \frac{\tilde{K}}{2}\sin 2\theta = h\sin\theta + \alpha\dot{\theta} \qquad (1)$$

where
$$\tilde{K} = \frac{K_{ac}(x,y)}{K^0_{ac}} = \begin{cases} 1, & \tilde{x} < \tilde{x}_1, \tilde{x} > \tilde{x}_2, \ \tilde{y} < \tilde{y}_1, \tilde{y} > \tilde{y}_2 \\ \tilde{K}, & \tilde{x}_1 \le \tilde{x} \le x_2, \ \tilde{y}_1 \le \tilde{y} \le \tilde{y}_2 \end{cases}$$

is the function defining the anisotropy distribution in magnetics (in this case, in the form of parallelepiped with width $\tilde{W}_x = \tilde{x}_1 - \tilde{x}_2$ and length $\tilde{W}_y = \tilde{y}_1 - \tilde{y}_2$ and depth $\tilde{K}$); $h = 2\frac{H_d H_Z}{H_K H_E}$, $\alpha = 2\alpha_0\sqrt{\frac{H_E}{H_K}}$ – non-dimensional damping parameter, $H_E = \frac{a}{4M_0}$ $H_d = \frac{d}{2M_0}$, ; d – Dzyaloshinsky interaction parameter, H_z – component of the external magnetic field.

To investigate the DW nonlinear dynamics, let numerical method of iteration for the explicit scheme be used. At the starting point of time, the initial distribution of magnetization in the form of a Neel DW $\theta(x,y) = 2arctg\left(e^x\right)$ was set with boundary conditions $\theta(\pm\infty, y) = 0, \pi$, $\theta'(\pm\infty, y) = 0$. Then, magnetic field being switched on, using the net in coordinate [-400...400, -400...400] and

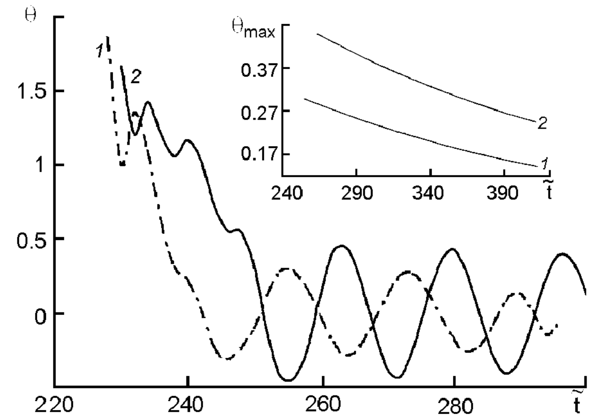

Fig. 2. Time dependence of angles θ and θ_{max} (inset) in the MACI region center for the case of Fig. 1.(*1*– motion of DW in external magnetic field; *2* – inertial motion of DW $h = \alpha = 0$).

taking time as the iterative parameter (following the condition of explicit scheme convergence) the state in the next moment of time was calculated, wherefrom the basic characteristics of the dynamic DW were obtained. The MACI area was lagged in time enough to attain a stationary value $\tilde{\upsilon}$ of the DW velocity corresponding at a high accuracy to the well-known formula [8]:

$$\tilde{\upsilon}_{\text{limit}} = \frac{\chi}{\sqrt{1+\chi^2}}, \qquad (2)$$

where $\chi = h/\alpha$. All the results represented in this paper were investigated for the cases of small dissipation ($\alpha = 10^{-2}$).

From numerical calculations, the dependences $\theta(x,y,t)$ for various values of h and MACI parameters were found. As an example, illustrated be the transition of a DW accelerated to a constant velocity through two-dimensional NCMA area with parameters $\tilde{W}_x = 2$, $\tilde{W}_y = 2$, $\tilde{K} = -1.5$, $\tilde{\upsilon}_{\text{lim}it} = 0.6$, $h = 0.022$ (Fig. 1).

At the first stage ($\tilde{t} = 230 \div 245$), after the DW center crossing of MACI region, a magnetic inhomogeneity in the form of a nonlinear wave with bell-shaped oscillating function $\theta(x,y,t)$ is generated in this region. Here, the emission of three-dimentional spin waves and the appearance of solitary bending waves on the DW is observed. On the second stage ($\tilde{t} > 240$), the quasi-periodic character of functions $\theta\ (x^*, y^*, t)$ is traced, where x^*, y^*- is the centre of NCMA region, with period $\tilde{T} = \dfrac{T}{\delta_0/c} = 16.6$ (Fig. 2, curve *1*). It is to note that a similar situation (with some changes) is also observed when the DW passes inertially the MACI region (for instance $\tilde{T}^* = 17.2$, Fig. 2, curve *2*). The radial symmetry to functions $\theta(x,y,t) = \theta(r,t)$ is also tracked. Thus, the magnetic inhomogeneity being generated in MACI region can be associated with the solution of the "weakly emitting pulson" type sine-Gordon equation [9]. The amplitude of the formed pulson decreases slowly with time (Fig. 2, inset).

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Магнітні неоднорідності типу солітонів та бризерів у магнетиках з локальною неоднорідністю анізотропії

Е.Г.Екомасов, Ш.А.Азаматов, Р.Р.Муртазин

Із застосуванням числових методів розглянуто особливості проходження доменної межі через двовимірну область неоднорідності константи магнітної анізотропії. Досліджено зародження та еволюція локалізованої магнітної неоднорідності типу пульсону у цій області.