ON THE 60th BIRTHDAY OF KOTEL’NIKOV INSTITUTE OF RADIO ENGINEERING AND ELECTRONICS, RUSSIAN ACADEMY OF SCIENCES

The Second-Order Magnetization Precession in an Anisotropic Medium. Part 2: The Cubic Anisotropy

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Received November 20, 2012

Abstract—The second-order precession of the magnetization vector in a normally magnetized magnetic plate with the cubic anisotropy is considered for the [001], [011], and [111] orientations of the axes of a cubic cell along the static field. The precession pattern of the forced oscillation in the form of a large ring and small rings located along the envelope is obtained. A relationship between the observed high- and low-density groups of small rings and the spatial position of the [111] easy magnetization axes is revealed and explained on the basis of the energy model of the potential. It is found that the phenomenon is highly sensitive to the orientation of cubic axes, the anisotropy constant, and the intensities and directions of the static and alternating fields. It is reported that the observed phenomena can be used in practice.

DOI: 10.1134/S1064226913080081

INTRODUCTION

It is shown in studies [1—3] that a high-amplitude precession of the magnetization vector with angles of deflection from the field direction as large as 50°–60° can be observed in a normally magnetized ferrite plate. In the presence of a static field with the intensity below the demagnetization value, conditions for the second-order precession of the equilibrium position are formed. During this precession, the magnetization vector participates simultaneously in two precession motions: about the equilibrium position and about the field direction [4]. The period of this precession exceeds the period of the exciting field more than by an order of magnitude, and the precession pattern has the form of a circular ring uniformly filled by small rings along the generator. To explain this motion of the magnetization vector, we propose a vector model and an energy model that enable us to describe various aspects of the phenomenon.

Various precession modes are revealed in [5], and it is shown in [6, 7] that high- and low-density groups of small rings are observed in the precession pattern in the presence of a static or an alternating field.

In study [8], the precession of the equilibrium position is considered in the presence of a uniaxial anisotropy whose easy magnetization axis deflects from the normal to the plate plane. The high- and low-density groups of small rings observed in this case are explained on the basis of the energy model. It is shown that the high- and low-density groups of small rings can be compensated by a transverse static field and that the phenomenon is highly sensitive to the anisotropy axis orientation and the anisotropy constant. The possibility of practical application of the observed phenomena is indicated.

This study continues study [8] and is devoted to the investigation of the precession of the magnetization equilibrium position in a magnetic plate with a cubic anisotropy having various orientations of the [111] cubic easy magnetization axes relative to the plate plane.

1. GEOMETRY OF THE PROBLEM

Consider a normally magnetized ferrite plate with a cubic magnetic anisotropy. The general geometry of the problem is illustrated in Fig. 1. The ferrite plate is magnetized by static field $\vec{H}$, perpendicular to the plate plane, and alternating field $\vec{h}$ is applied in this plane. The $Oxy$ plane of Cartesian coordinate frame $Oxyz$ coincides with the plate plane, and the $Oz$ axis is perpendicular to it.

We consider a cubic crystallographic cell of the material of the plate and the following three variants (schematically shown in Fig. 1) of the orientation of the cell relative to the plate plane:

(i) the [001] orientation: one of the [001] axes that is a cube’s edge is oriented along the normal to the plate plane, i.e., along the $Oz$ axis, and the $Ox$ and $Oy$ axes are oriented along the two other edges of the cube;

(ii) the [011] orientation: one of the [011] axes, i.e., the diagonal of the cube’s face, is oriented along the normal to the plate plane or the $Oz$ axis, and the $Ox$ and $Oy$ axes are oriented along and perpendicularly to one of the cube’s edges, respectively;

(iii) the [111] orientation: one of the [111] axes, i.e., a spatial diagonal of a cube, is oriented along the normal...
to the plate plane or the Oz axis, and the Ox and Oxy axes are oriented along and perpendicularly to the projection of one of the cube’s edges on the Oy plane, respectively.

It is assumed that the spatial diagonals of a cube, i.e., the [111] axes, shown by solid lines inside cells are easy magnetization axes.

2. BASIC EQUATIONS

Next, we assume that static field $H_0$ is insufficient to orient the equilibrium magnetization vector perpendicularly to the plate plane. In [4], the circularly polarized alternating field

$$ h_x = h_0 \sin(2\pi F t), \quad h_y = -h_0 \cos(2\pi F t), \quad (1) $$

where $F$ and $h_0$ are the frequency and amplitude of the alternating field, respectively, is considered and it is shown that, when, under these conditions, the structure is excited by field (1), the precession of the equilibrium position can occur under certain circumstances. In this situation, the magnetization vector precesses at the excitation frequency about the equilibrium position and the equilibrium position itself precesses about the static field direction at a frequency much lower than the excitation frequency.

To solve the problem on the dynamic behavior of the magnetization vector, we follow the approach from [4] and apply the Landau—Lifshitz magnetization motion equations with the dissipative term in the Hilbert form [9]

$$ \frac{\partial m_x}{\partial t} = -\frac{\gamma}{1 + \alpha^2}[(m_x + \alpha m_y m_z)H_{ex}] $$

$$ - (m_z - \alpha m_y m_x)H_{ey} - \alpha(m_y^2 + m_z^2)H_{ex}; \quad (2) $$

$$ \frac{\partial m_y}{\partial t} = -\frac{\gamma}{1 + \alpha^2}[(m_y + \alpha m_z m_x)H_{ey}] $$

$$ - (m_x - \alpha m_z m_y)H_{ex} - \alpha(m_x^2 + m_z^2)H_{ey}; \quad (3) $$

$$ \frac{\partial m_z}{\partial t} = -\frac{\gamma}{1 + \alpha^2}[(m_z + \alpha m_x m_y)H_{ez}] $$

$$ - (m_y - \alpha m_x m_z)H_{ex} - \alpha(m_y^2 + m_x^2)H_{ez}; \quad (4) $$

where $\hat{\mathbf{m}} = \hat{\mathbf{M}}/M_0$ is the normalized magnetization vector, $M_0$ is the saturation magnetization, $\gamma$ is the gyromagnetic ratio ($\gamma > 0$), and $\alpha$ is the attenuation parameter of the magnetization precession.

The effective fields entering these equations have the form

$$ H_{ex} = h_x + H_{ax}; \quad (5) $$

$$ H_{ey} = h_y + H_{ay}; \quad (6) $$

$$ H_{ez} = H_{oz} - 4\pi M_0 m_z + H_{az}, \quad (7) $$

where $H_{ax}$, $H_{ay}$, and $H_{az}$ are the anisotropy field components determined by the orientation of the crystallographic cell.

The effective anisotropy fields are generally determined from the formula

$$ H_{ai} = -\frac{\partial U_a}{\partial M_i} = -\frac{1}{M_0} \frac{\partial U_a}{\partial m_i}, \quad (8) $$

where $U_a$ is the density of the cubic anisotropy energy for a given orientation of the crystallographic cell.

Basic equations (2)–(4), used for the solution of the problem, are represented in coordinate frame Oxyz associated with the direction of the static field and the plate plane. However, the density of the cubic anisot-