Journal of Magnetism and Magnetic Materials 401 (2016) 200–208

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Magneto-optical mapping of elementary topological configurations of inhomogeneous magnetic fields

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ARTICLE INFO

Article history:
Received 16 August 2015
Received in revised form
7 October 2015
Accepted 8 October 2015
Available online 13 October 2015

PACS:
85.70.Sq
02.40

Keywords:
Magneto-optical images
Indicator films
Singular points
Poincare Index

ABSTRACT

Magneto-optical images (MO) of projections of an inhomogeneous magnetic field on a magnetic indicator films plane were studied experimentally and by means of modeling. Inhomogeneity of the field clearly displays itself in the planar component distribution of this vector field by the presence of singular points and is clearly revealed by the MO-images in longitudinal sensitivity. The topological structure of the singular points of the field (Poincare Index) manifests itself in the peculiarities of the intensity distribution of the magneto-optical images. These peculiarities can serve as identifiers of “sink”, “source” and “saddle”-type singular points. The influence of a homogenous bias field on the change in topological properties is demonstrated. Changes in the geometry of the magnetic system also change the topology of the magnetic field; this is reflected in the number and the properties of the singular points of the MO-images.

1. Introduction

Epitaxial iron-garnet films with in-plane anisotropy are successfully applied for visualization of inhomogeneous magnetic fields [1]. Registration of the component normal to the indicator film plane of the inhomogeneous magnetic field is made using the Faraday effect. Under certain conditions it is possible to carry out the topography of the out-of-plane component and to restore the magnetization pattern in the magnetic field source [2]. This method of detecting the inhomogeneous magnetic field is limited by the lack of information about the value and the direction of the planar component of the inhomogeneous field.

Using magnetic metal films with in-plane anisotropy for the visualization of inhomogeneous magnetic fields allows for the gathering of information about the distribution of vertical (H_z) and planar (H_x,H_y) components of the field [3]. In the general case in the course of visualization of the inhomogeneous magnetic field in the geometry of the longitudinal Kerr effect, the intensity of a magneto-optical (MO) image is determined by three components of the magnetization strength of the indicator film [4]

$$I = A_0 + A_1 m_z + B_1 m_l + C_1 m_t + A_2 m_z^2 + B_2 m_l^2 + C_2 m_t^2 + D_2 m_z m_l + E_2 m_z m_t + F_2 m_l m_t. \quad (1)$$

Here $m_z = J_z/J$, $m_l = J_l/J$, $m_t = J_t/J$ are the normalized magnetization components of the indicator film, J_z is perpendicular to the indicator film, J_l is parallel to the plane of light incidence (PI), and J_t is perpendicular to the plane of light incidence, A_0 – background light, A_1, B_1, C_1, A_2, B_2, C_2, D_2, E_2, F_2-magneto-optical parameters. They depend on the properties of the indicator film and the polarizer/analyzer installation. If the contrast is optimized, they are fixed for the given conditions of observation.

Subject to compliance with a number of requirements the intensity is a linear function of the magnetization components [4]

$$I = A_0 + A_1 m_z + B_1 m_l + C_1 m_t. \quad (2)$$

Linearity allows the restoration of the vector field of magnetization m_z, m_l, m_t using MO-images [4].

If anisotropy in the film plane is low, then the planar component of the magnetization is parallel to the field in the plane of the indicator film ($\mathbf{H}_p$ (x,y)): $\mathbf{m}_p \parallel \mathbf{H}_p$, ($\mathbf{m}_p = \mathbf{m}_l + \mathbf{m}_t$). Under these conditions it is possible to obtain additional information on the spatial distribution of the field [5].

In the present work the analysis of mapping of projections of elementary topological configurations of the three-dimensional inhomogeneous magnetic field ($\mathbf{H}_{in}(x,y,z)$) on the indicator film plane by MO-images is carried out. Special attention was paid to the singular points of the MO-images revealing in an accentuated manner the singular points of the planar (H_x,H_y) components of the field $\mathbf{H}_p$ (x,y).

http://dx.doi.org/10.1016/j.jmmm.2015.10.011
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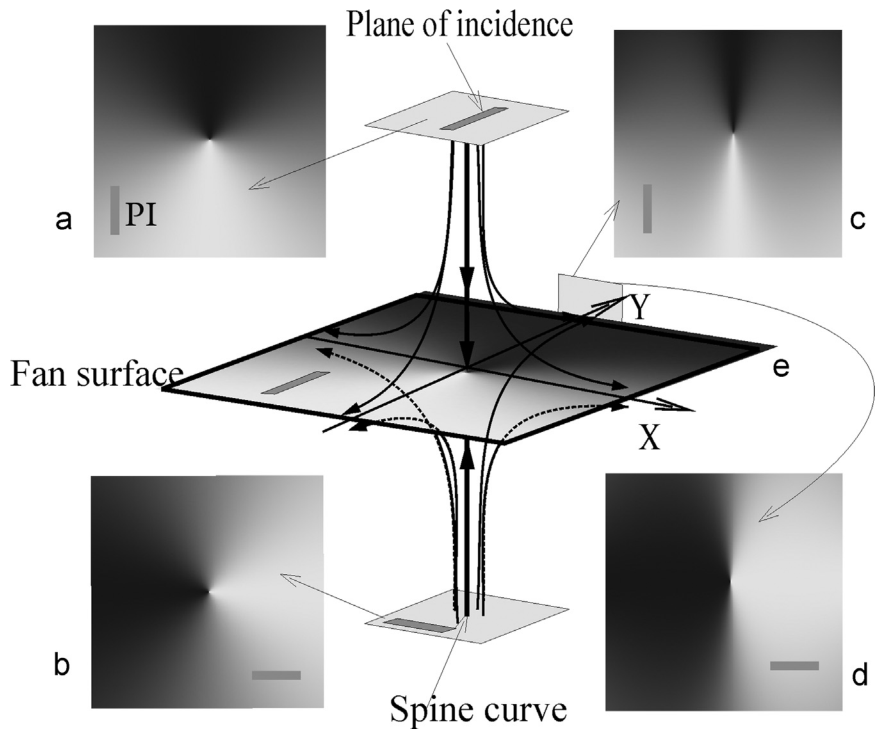

Fig. 1. Three-dimensional null (singular) point of the inhomogeneous magnetic field and the corresponding models MO-images.

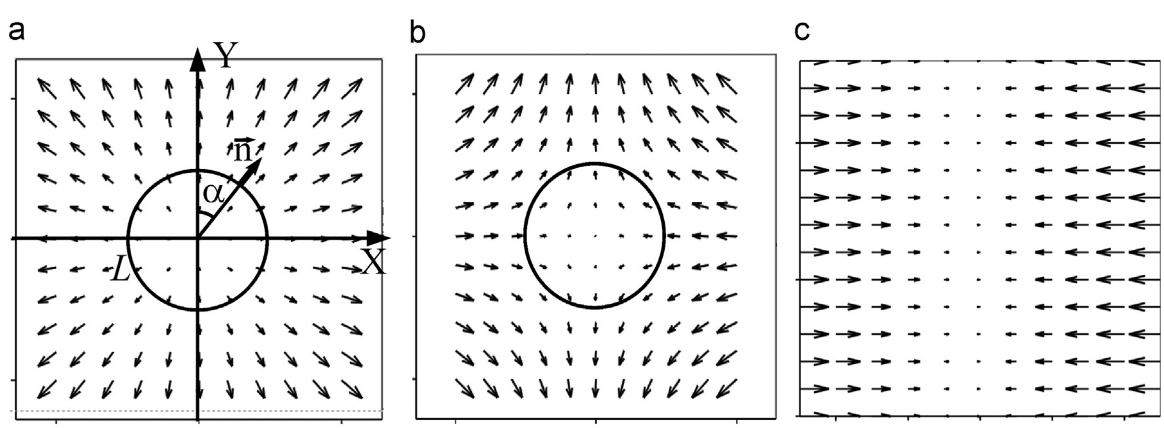

Fig. 2. Planar component vector fields near the singular point of So-type (a), Sa-type (b) and the singular line (c).

2. Experimental procedures and modeling

2.1. Elements of the inhomogeneous magnetic field structure

The global structure of the complex three-dimensional magnetic field $\mathbf{H}_{in}(x,y,z)$ includes null (singular) points and the network of spine curves and separatrix fan surfaces [6]. The 3-D null (singular) point is an elementary structural item of the skeleton of the inhomogeneous magnetic field (Fig. 1). This situation occurs when streams in two coaxial vector tubes are directed towards each other.

Projection of the vector field $\mathbf{H}_{in}(x,y,z)$ on some cutting plane results, in the general case, in increasing the number of singular points of the vector field in the plane where $\mathbf{H}_p(x,y)=0$, due to the occurrence of the singular points that are, from the topological point of view, “source” (So) points or “sink” (Si) points. This situation occurs if the cutting surface is perpendicular to the spine (Fig. 1(a), (b) and (e)).

Near the singular points the function $\mathbf{H}_p(x,y)$ can be expanded in the Taylor series

$$H_x = b_{xx}x + b_{xy}y,\ \ H_y = b_{yx}x + b_{yy}y, \tag{3}$$

where

$$b_{xx} = \partial H_x/\partial x,\ b_{xy} = \partial H_x/\partial y, \tag{3a}$$

$$b_{yx} = \partial H_y/\partial x,\ b_{yy} = \partial H_y/\partial y\cdot \tag{3b}$$

In the vicinity of the So and Si-type singular points $b_{xy}, b_{yx}=0$, a plane vector field is described in the following form:

$$\vec{\mathbf{H}}_p = b_{xx}x\vec{\mathbf{i}} + b_{yy}y\vec{\mathbf{j}}, \tag{4}$$

(Fig. 2(a), $b_{xx}=b_{yy}=1$). If the cutting plane is parallel to the spine, the projection will include a saddle (Sa) singular point; force lines near this point are hyperbolic

$$\vec{\mathbf{H}}_p = b_{xy}y\vec{\mathbf{i}} + b_{yx}x\vec{\mathbf{j}}, \tag{5}$$

(Fig. 2(b), $b_{xy}=b_{yx}=1$).

For the visualization and the topological analysis of the vector field it is convenient to use the graphs of the normalized vector