INCREASING SENSITIVITY OF MAGNETO-OPTIC IMAGES USING MATLAB

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Abstract

The scope of the present paper is the image contrast improvement study, using MATLAB, of magnetic-optical images captured by systems capable to fructify KERR effects (polar, transversal or longitudinal).

Important for the understanding of the origin of magnetic properties and technological application of magnetic materials is the ability to observe the *magnetic domain structure*. One method, practiced since decades, is magnetic-optical microscopy using conventional imaging optics. Magnetic optical microscopy is one of the most versatile techniques to image magnetic domains and magnetization processes. The method is based on the magnetic-optical *Faraday or Kerr effect*, i.e. the rotation of linearly polarized light in dependence of the magnetization direction on transmission or reflection from a non-transparent sample, respectively.

The Image Processing Toolbox within MATLAB environment allows us to process images coming from a microscope capable to acquire magnetic-optical images. The processing consists in several steps:

1. acquire the reference image – at saturation point;
2. acquire images at preset intensities of magnetic field;
3. subtract bit by bit reference image from images acquired at step 2;
4. analyze images pixel by pixel and compute the black and white ratio;
5. display the results.
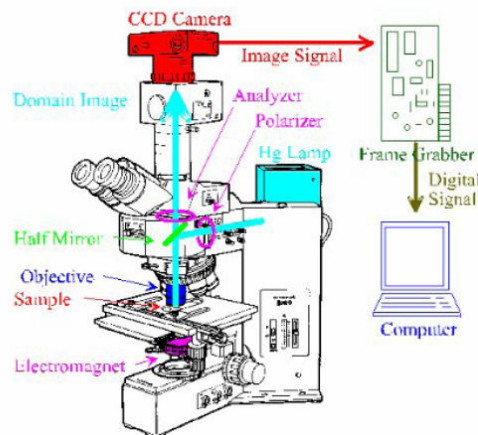
Experimental setup

The final goal of our researches is to achieve a quantitative optical magnetometer MOKE (Magnetic – Optical – KERR - Effect) type. This goal is reached by evaluation of the black and white ratio from images acquired at different levels of magnetic field, when the history of the applied magnetic field follows a sine or an angle wave.

1. Design of magnetic field source

In order to "design" the permanent magnets, is very useful to study their behaviour for different working conditions: (different temperatures and working media), but, in the case of the sintered permanent magnets based on Nd-Fe-B alloys, also the stability in the working point of the magnet is essential [1-3]. In order to describe the permanent magnet stability is necessary to analyse the following processes:

-   the irreversible changes of the remanence, due to the dependence of the spontaneous magnetization, M_S, with the temperature;
-   the irreversible changes of the magnetic parameters. The magnets with hysteresis curves characterised by a high squarness ratio presents, after 1000 h ageing, low irreversible losses, in comparison with the initial state. This losses, caused, main by the coercivity changes with the temperature, depends on the allure of the demagnetisation curve and, consequently, on the preparation way of the permanent magnets. When the demagnetisation curve have a higher value for the squarness ratio, than the losses are lower;
- the structural changes, due to the corrosion, for example, changes which damage irremediably the magnetic performances.

In the research field of the magnetic materials characterization, is very important to use stabilized sources for generate high magnetic fields. Commercial sources with electromagnets, have electrical drift, are very expensive and have more other inconveniences. One of the solutions for all these problems is the generations of the magnetic field with Halbach's cylinders system [4]. Permanent magnet based Vibrating Sample Magnetometer was develope by J.M.D Coey and co-workers. A field of fixed direction and variable amplitude is generated in the cavity by making two nested Halbach's cylinders made of Nd-Fe-B to rotate in opposite directions. Each cylinder generates a field of strength H_O in the bore and the resulting field varies with the angle of rotation a as $H(a) = 2H_O\cos a$, making a full period for a 360° rotation of the cylinders.
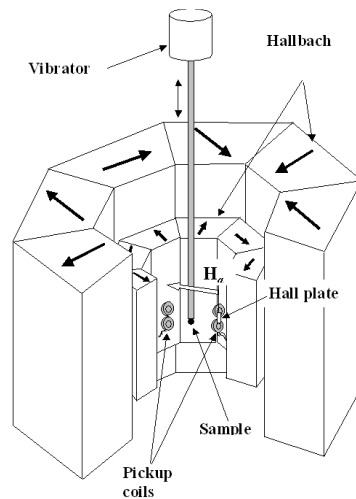
The advantages of permanent magnets over electromagnets for these purposes are that the ring structures are comparatively light and compact and that they require no power supply or cooling.

3. Experimental and simulations of magnetic field sorce

The sintered permanent magnets based on Nd-Fe-B were obtained by usual methods, specific to the Powder Metallurgy: decrepitating (thermal treatment in hydrogen atmosphere) of the cast alloys, ball milling, wet pressing in the presence of an external field, $H_{ext} \sim 10$ kOe, followed by thermal treatments, during 1 - 2 h, for sintering at temperatures in the range $1060^oC - 1100^oC$ and for annealing: 600 - 630°C, respectively.

The Nd-Fe-B samples were prepared, changing the chemical composition and the microstructure of the hard magnetic material.

Using the "two alloys" method, by adding of Dy_2O_3 or metallic Dy, we have performed the improvement of the permanent magnets microstructure. We have used two master alloys:

- A1: $Nd_{24}Dy_5Fe_{68.6}Al_{0.4}B_1$ and

- A2: $Nd_{28.5}Dy_5Fe_{62.6}Al_{0.4}B_1$ (% weight), and also different Dy_2O_3 and Dy amounts.

We prepared, also, magnetic samples with different Dy_2O_3 amounts, using the "single alloys" method [5]

We have realized a analysis of the temperature variation of the main magnetic characteristics: $_JH_C$, B_r, $(BH)_{max}$. The temperature behavior of the prepared sample was characterized in two ways:

- by the performing of the temperature dependence of the coercivity, $_JH_C$, using a vibrating sample magnetometer. The samples - 2 mm diameter and 2 mm height – have a demagnetization factor: 0.32 were measured in a 10 kOe magnetic field and,

- by measurements of the irreversible losses for different dimensional ratios, using the fluxmetric method, in open / closed magnetic circuit.

In the back of the preliminary dimension and optimize through mathematical modulations of the structure of the field (the calculation program Femm 2D), are definitive the following characteristics of these two concentrically cylinders from magnetic sectors sintered NdFeB (B_r=1.188T, $\mu_0H_c\cong2T$), $BH_{max}\cong$ 200 kJ/m^3) :

-the external diameter of external cylinder: 130mm

- the inner diameter of external cylinder : 76.4mm

- the external diameter of inner cylinder : 69.6mm

- the inner diameter of inner cylinder : 40mm

-number of the sectors (for each cylinder) 16pcs

-the height of the cylinders 35mm

In fig. 2 is shown the sectorial structure with the orientation of the magnetization for each cylinder, and in the following figures, is shown the structure of the field for the different angles between axes of the cylinders and the diagrams of the variation after characteristic ways for the uniformity of the field.

It rotates the inner cylinder that the external with the following angles:
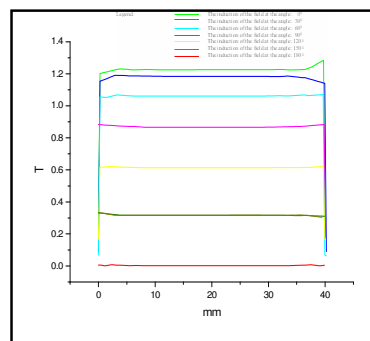
Fig 2. The curves of the induction on the unity length, in the useful space, at the different angles between resulting vectors of the magnetization for two cylinders.

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4. The KERR magneto-optic Microscope

The Kerr effect is the change in the optical wave properties of reflected polarized light produced when the surface is magnetic. The optical ellipticity, the polarization azimuth, and the amplitude of the incident polarized light can be affected **[5].** Magnetic contrast between domains is possible because these magnetooptic changes depend upon M. Figure 3. illustrates the three types of Kerr effect geometrically. The polar Kerr effects refer to changes due to M-components perpendicular to the surface. The longitudinal and transverse Kerr effects are named for the changes that are sensitive to the plane of optical incidence. The transverse Kerr effect is a change in the reflected light amplitude rather than phase. It is useful for ultraviolet wavelength where optical polarizers are ineffective

Figure 3) a) polar Kerr effect; b) longitudinal Kerr effect; c) transversal Kerr effect [6]
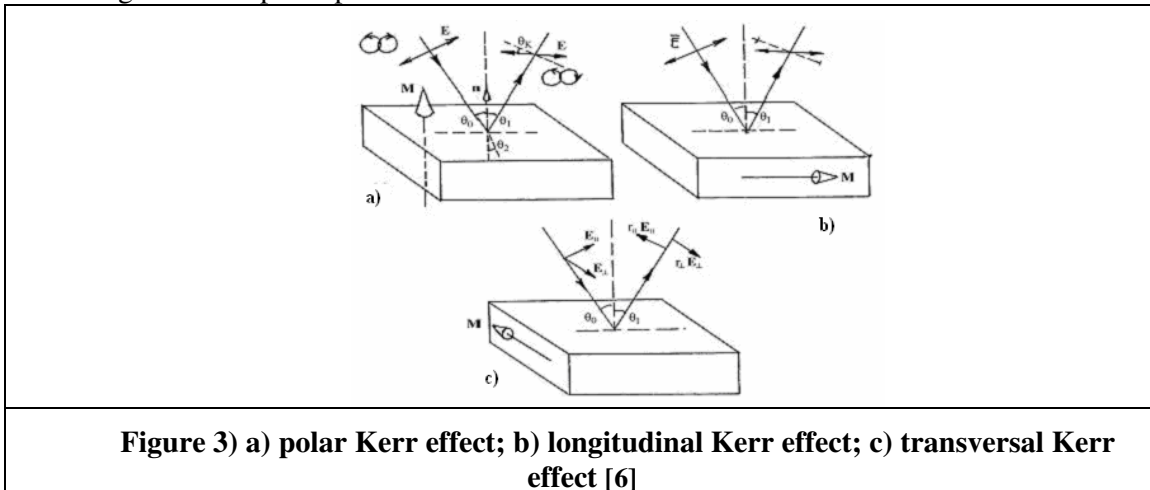
5. Kerr images and discussions:

For magneto-optical images processing, witch shows the Kerr effects, we have used Matlab environment and Image Processing Toolbox included in it.

The program made include a graphical interface witch allows rapid access to the images witch must be selected for further processing and to the information about selected and processed images fig.4.
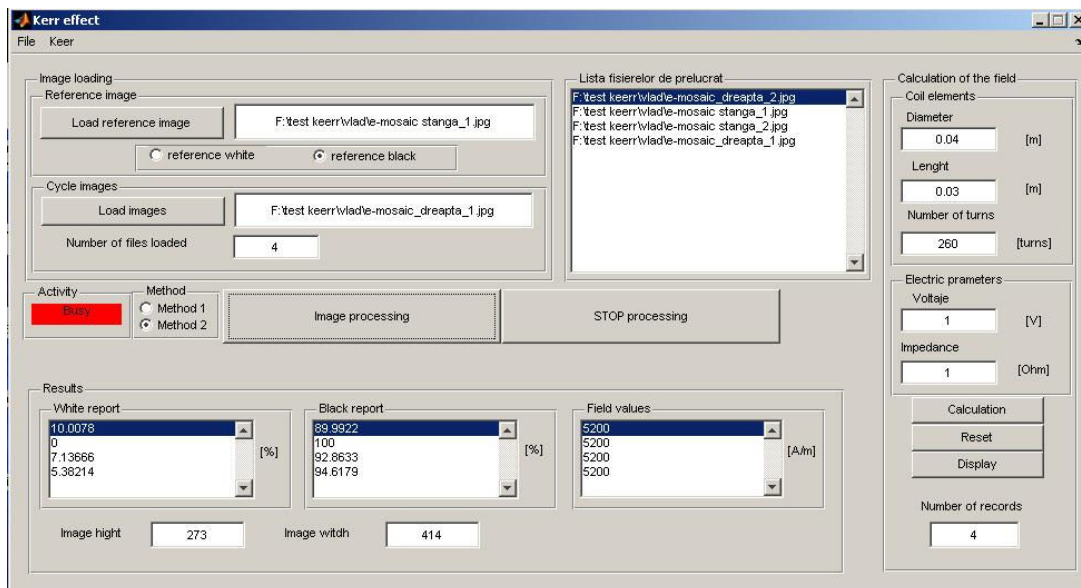
Figure 4 Panel of program

The program has the following windows available:

- Main window;
- A window in witch are shown the images selected for processing and resultant image;
- A window in witch is represented the chart for an entire cycle (hysteresis loop).

Graphical interface is made with the help of GUIDE included in Matlab.

The program uses two methods for processing images magneto-optical:

1) First method – processing of images presume:

   a. Loading of reference image(the image is acquired when the material has reached his magnetic saturation point) is possible with the help of the function "imread";

   b. Loading of the selected images correlated with the magnetic field values with the help of the function "imread";

   c. Subtraction of the reference image from the selected image with the help of the function "imabsdiff";

   d. Convert the image to a binary image (black and white), based on level(level = graythresh(image) computes a global threshold (level) that can be used to convert an intensity image to a binary image with "im2bw" function. Level is a normalized intensity value that lies in the range [0, 1]. The graythresh function uses Otsu's method, which chooses the threshold to minimize the intraclass variance of the black and white pixels.) (The output binary image black and white has values of 1 (white) for all pixels in the input image with luminance greater than level and 0 (black) for all other pixels) with the help of the function "im2bw";

   e. Calculation of the number of black and white bites contained in the image with the help of the function "sum" witch calculate the number of white bites.

   f. Scaling the number of black and white bites to the dimension of the image.

   g. Displaying the results: percents of black and white for each image processed;

   h. Plotting the chart (hysteresis loop) for these values with the help of the function "plot".

2) First method – processing of images presume:

   a. Loading of reference image(the image is acquired when the material has reached his magnetic saturation point) is possible with the help of the function "imread";

   b. Loading of the selected images correlated with the magnetic field values with the help of the function "imread";

   c. Subtraction of the reference image from the selected image with the help of the function "imabsdiff";

   d. Calculation of the RGB average for the entire image with the help of the function "impixel";

   e. Scaling the RGB average to the maximum value of the visible spectrum considered to have 255 for the white colour and 0 for black.

   f. Displaying the results: percents of black and white for each image processed;

   g. Plotting the chart (hysteresis loop) for these values with the help of the function "plot".

The program allows for the two windows (the window in witch the images are shown and the one in witch the chart is represented) printing and saving the dataset.

In the picture below (fig.2) are shown four images:

- First image (left – top corner) is the reference image;
- Second image (right – top corner) is an image from the hysteresis loop;
- Third image (left – bottom corner) is the subtracted image.
- Fourth image (right – bottom corner) is the converted image in black and white after subtraction.

From our images is can been se that is difficult to eliminate one of the Kerr effect, in practice all three effects occurs in the same time.

Is important to optimize contrast of images by summation of frames or summation of different images, and for experience the contrast and signal-noise ratio is still good when source intensities are weak or camera noise is high.

They are two important factors which perturb the quality of domain images: laboratory vibrations and stray field fields from magnetic parts of the microscope. If one eliminate all factors that can perturb the quality of image is possible to switch from qualitative images to quantitative images, this work will be our aim for the future.

ACKNOWLEDGEMENTS

6. References:

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