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Fast magnetic field mapping of permanent magnets with GMR bridge and Hall-probe sensors

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Abstract

The commercial MagScan X-Y scanning system, that uses either a Hall-probe or a giant magnetoresistance (GMR) bridge sensor, has been used to perform fast magnetic field mapping of ring-shaped permanent magnets. Maps of the three magnetic field components have been obtained separately from both types of sensors. Comparison between these maps has allowed a direct evaluation of the efficiency of each type of sensor as a quality assessment tool in the production of permanent magnets.

Keywords: Magnetic field mapping; GMR bridge sensor; Hall sensor; Non-destructive testing

1. Introduction

Fast magnetic field mapping scans can be proved invaluable in the sputtering industry for the characterization and calibration of magnetron guns, and the characterization and quality control of sputter-grown magnetic films. Also, it can be used as a quality assessment tool in production of complex multipole magnets or complex assemblies such as loudspeakers or photocopier rollers. Recently, the use of giant magnetoresistance (GMR) Co/Cu multilayer sensors in magnetic field mapping of a ring magnet has been demonstrated [1,2]. The previous study [2] was based on a slow (8 h per scan) X-Y scanning system and a 2D array sensor with 2×4 units, where a common current flow pass through all GMR sensing elements and the induced voltage drop across each element is measured. This simple magnetic sensor design led to 3D mapping of a dipolar magnetic field with an output voltage lying in the microvolts range whereas a Hall sensor gave output signals of the order of millivolts. Today, the best utilization of GMR materials for magnetic field sensors appears to be in Wheatstone bridge configurations. Here, we demonstrate a commercial X-Y scanning system that uses either a Hall-probe or a GMR bridge sensor to perform high-resolution magnetic field mapping of permanent magnets within minutes.

2. Experimental details

In this study we have used NVE (Nonvolatile Electronics) AA004-02 GMR bridge sensor. NVE GMR Magnetic Field AAxxx series sensors are fabricated from four photo-lithographically patterned GMR resistors and utilize small magnetic shields that are plated over two of the four equal resistors in a Wheatstone bridge protecting these resistors from the applied field and allowing them to act as reference resistors. The two remaining GMR resistors are both exposed to the external field. The bridge output is therefore twice the output from a bridge with only one active resistor. The commercial flatbed MagScan system used is a fast mechanical X-Y scanning device that measures simultaneously the *X, Y,* and *Z* Cartesian components of a magnetic field in real-time. Controlled by PC, its standard configuration uses a fast moving head with three Hall-probe sensors that can measure up to 40.000, 3D field strength data points at a maximum resolution of 0.1 mm. The AA004-02 sensor has been attached next to the Hall sensors. The so-called [3], EDDIX multi-sensor card link into MagScan and its upgraded software were used for data collection and manipulation from the GMR sensor. The test object was placed beneath the sensors at a distance of 5 mm. Both types of sensors were mounted on a vertical arm that was fixed on the moving part of the X-Y stage. An area of 100 mm × 100 mm was scanned over the magnet with a constant step of 0.5 mm along the *X*- and *Y*-directions. The

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sensor was scanned along the *x*-axis and then the *x*-scan was repeated for different positions along the *y*-axis.

3. Results

Fig. 1 shows the magnetic field mapping of a ring magnet as measured by (a) the GMR sensor placed with its sensitivity axis along the *z*-axis, (b) the GMR sensor in the same direction but shielded by a μ-metal foil placed parallel to the sensor plane and (c) the *z*-axis response of the Hall-probe. The GMR sensor (Fig. 1a) gives a clear imaging of the magnetic field even in the regions away from the center of the ring magnet due to its high sensitivity. The ring shape of the magnet creates a ring area of minimum field approximately 1.5 cm away from the center followed by a ring of maximum field with a radius of 2 cm. However, due to the saturation of the sensor, all the detail is lost in a central area having a radius of 1 cm. This should be compared to the image obtained by the Hall sensor in Fig. 1c. There, the central area is characterized by a field of around 24–32 kA/m rimmed by a ring of maximum field above 32 kA/m at a distance of 1 cm from the center after which field drops abruptly with distance. The inefficiency of reproducing the details of the central region is a combined result of the low saturation field of the GMR sensor and its sensitivity to the other components of the field (perpendicular to the sensitivity axis).

A compromise between having advantage of the GMR sensor in mapping the low field region away from the center and that of the Hall sensor to image accurately the higher field regions can be obtained by shielding the GMR sensor from the field components perpendicular to its sensitivity axis. In the case of the shielded GMR sensor (Fig. 1b) the field mapping is closer to that obtained by the Hall sensor. However, there is still a central region of radius 1.5 cm in which the field appears saturated to its maximum value.

A second test object is a ring magnet, consisting of the same material and having the same dimensions with the sample shown in Fig. 1, that creates a quadrupolar magnetic field. Figs. 2 and 3 show the magnetic field mapping of H_x, H_y, and H_z components that were measured by the Hall-probe and the NVE AA004-02 GMR bridge sensor, respectively. Since the GMR resistors respond mainly to the component of magnetic field along their long dimension [2], the H_x, H_y, and H_z components of the field have been measured in three successive scans by positioning the long axis

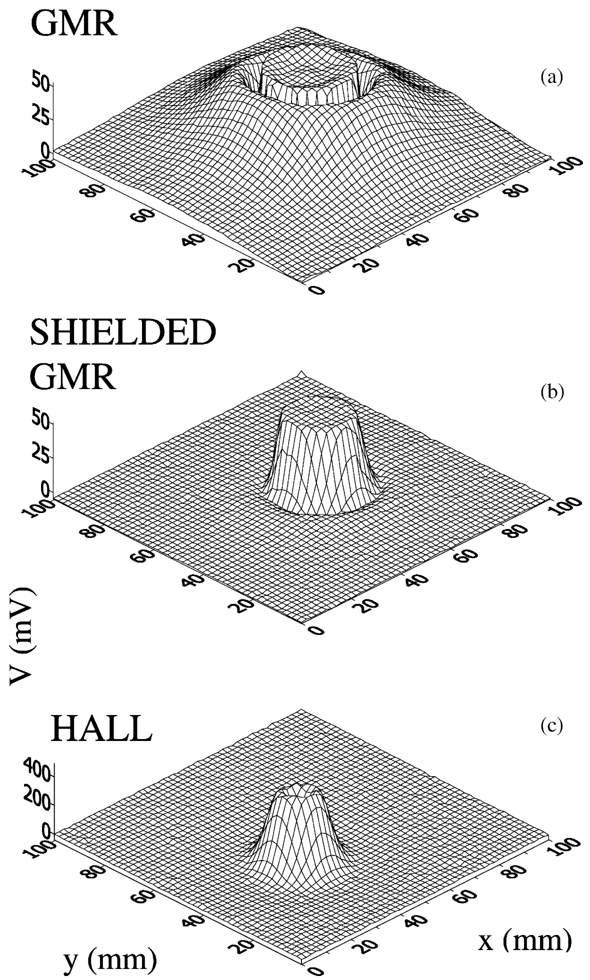

Fig. 1. Magnetic field mapping produced by (a) the GMR sensor placed with its sensitivity axis along the *z*-axis, (b) the GMR sensor in the same direction but shielded with a μ-metal foil that is placed parallel to the sensor plane and (c) the *z*-axis response of the Hall-probe.

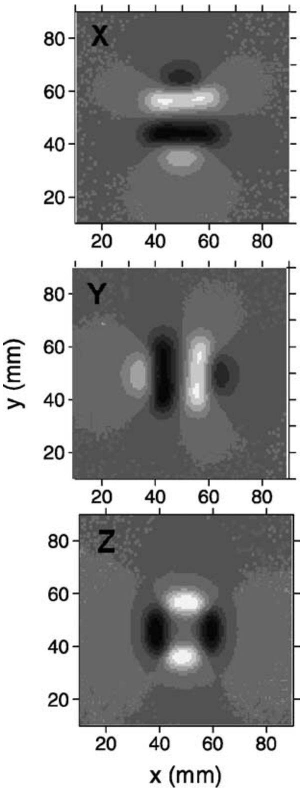

Fig. 2. The H_x, H_y, and H_z components of the magnetic field measured by the Hall-probe, where the gray scale plot varies between a maximum negative (white) to its positive (black) output voltage value.

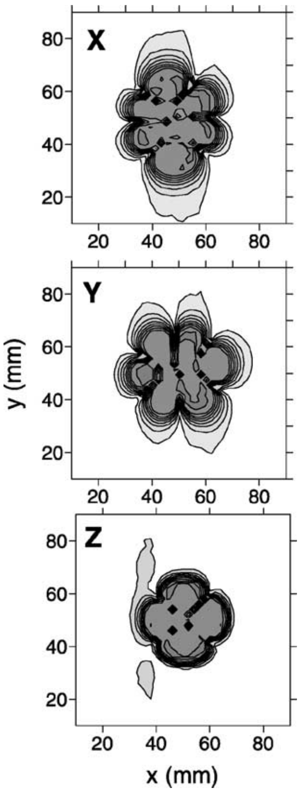

Fig. 3. The H_x, H_y, and H_z components of the magnetic field measured by the GMR bridge sensor, where the gray scale plot varies between zero (white) to a maximum positive (black) output voltage value in millivolts.

of the GMR sensor along the physical *X*, *Y*, and *Z* dimensions of the MagScan table. Each scan has been completed within 5 min. Since the GMR response signal is an even function of the applied field, the GMR sensor cannot distinguish changes of the field sign. Thus, the negative field regions that are detected by the Hall-probe (Fig. 2) appear as positive fields in GMR field maps (Fig. 3).

4. Conclusions

In summary, this study shows the importance of shielding in the use of a GMR bridge sensor for efficient field mapping of permanent magnets. In analogy to the case of a read voltage for arbitrary magnetic recording head field, where the voltage response from a sharp magnetic transition is just proportional to the horizontal component of the head field itself [3], it is shown that the shield should allow only the parallel field component along the sensitivity axis of the GMR bridge sensor.

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