Journal of ELECTRICAL ENGINEERING, VOL 57. NO 8/S, 2006, 185-188

MAGNETIC SENSOR ARRAY FOR INVESTIGATIONS OF MAGNETIC FIELD DISTRIBUTION

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Various magnetic sensor arrays are described - GMR sensor array, Hall sensor array and AMR sensor array. The applications of this last one are presented. The sensor matrix was designed for three various purposes: a) for test of the steel strip in $n \times 16$ points, b) for increase of the sensor output signal and to obtain the averaging effect, c) for improve of the speed of the scanning device.

Keywords: magnetic sensor, magnetic sensor array, scanning of magnetic fields, GMR sensors, AMR sensors.

1 INTRODUCTION

For investigations of magnetic field distribution various scanning systems have been developed – for example MagScan system [1], Magnetovision system [2,3] or Scanning Hall Probe Microscope [4,5]. For improve speed of the magnetic field investigations (especially in the case of varying fields) much better would be to use magnetic sensor array. Unfortunately in the case of magnetic sensor arrays we do not observe such progress as in the case of optical sensors (cameras with matrix larger than 10 Mega pixels or optical scanners with resolution better than 2400 dpi).

There are reported designs of magnetic sensor array composed of Hall sensors [6], MagFet sensors [7] or coil sensors [8], but there are not market available such sensors. Lately manufacturer of GMR sensors Nonvolatile Electronics Company presented design of sensor array (but to date also such sensors are not available). Thus at last investigators have to prepare such sensor matrix by themselves.

2 SENSOR ARRAY OF NVE

No doubt that the proposal of Nonvolatile Electronics is most promising. Thin film sensor technology is very convenient to prepare the sensor arrays because typically on one silicon wafer can be deposited even hundreds of sensors. Additionally nanotechnology helps in obtaining of very small sensors with sufficient output signal due to large coefficient of magnetoresistivity in GMR effect. To prepare the sensors NVE uses two kinds of GMR effects: SV (spin valve) with two thin film layers separated by conductor layer and more sensitive TMR (tunnelling magnetoresistance) with two thin film layers separated by insulator layer [9].

Figure 1 presents one of the sensor array designed by NVE [10,11,12]. The line of 2×16 GMR sensors (in half-bridge connection) is 80 μm long with sensors 1.5 μm wide and 6 μm high separated each other by 5 μm. Figure 2 presents parts of the 128-element array with dimensions 4.5 mm by 2 mm (obtained by simply clone 16-elements design). It is also possible to arrange the sensor to obtain two-dimensional investigations of magnetic field. Usually the bridges are connected in parallel with a common supply and output signals are multiplexed.

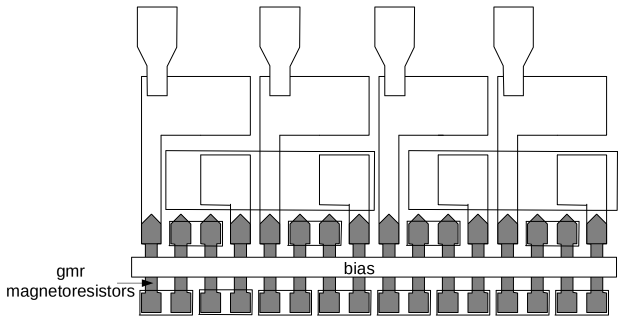

Fig. 1. The example of the design of 16 element array of NVE chip [11]

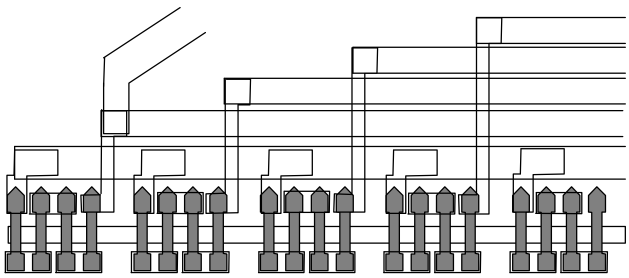

Fig. 2. The part of 128 element sensor matrix obtained by clone of 4 element sensor [11]

3 THE HALL SENSOR ARRAY DESIGNED BY TEAM FROM POZNAN

As long as the sensor array of NVE is not for sale various teams construct sensor array by themselves. To tell truth the advantage of this solution is that such sensor matrix is better adapted to specific problem. Figure 3 presents the Hall sensor matrix designed for investigations of rather large magnetic field in large area. This matrix was developed by team from Poznan University of Technology [13].

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ISSN 1335-3632 © 2006 FEI STU

The sensor matrix presented in Fig. 3 is composed of 16 × 16 Hall sensors AD22151 of Analog Devices (with sensitivity of about 5 mV/(kA:m) - each sensor supported by amplifier).

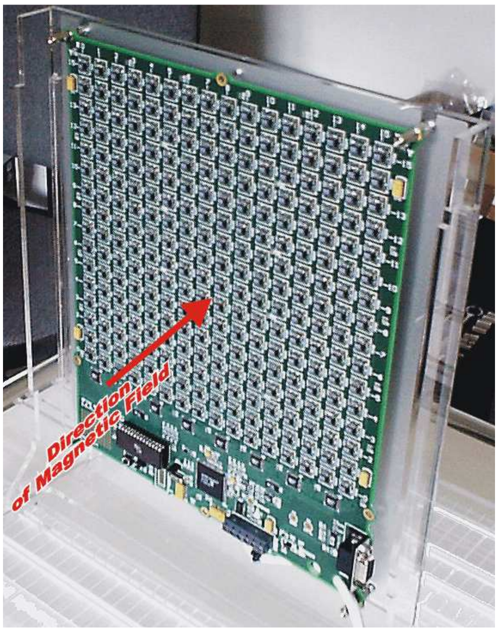


Fig. 3. The Hall sensor array designed by Porada et al [13]

Such sensors are integrated with appropriate electronics (circuit for temperature correction and gain circuit) therefore it is easier to realise the multiplexing the output signal of each individual sensor. Fig. 4 presents the control/multiplexing circuit of designed matrix.

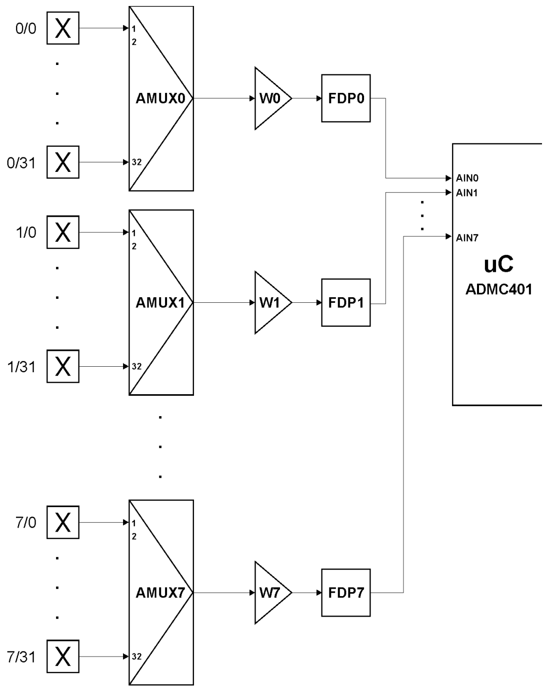


Fig. 4. The control/multiplexing circuit of sensor matrix (AMUX – analogue multiplexers, W – amplifiers, FDP – filters, µC – microcontroller) [13]

4 THE SENSOR MATRIX DESIGNED BY THE AUTHORS

Figure 5 presents the design of the sensor matrix developed by the author for testing of the electrical steels. 16 magnetoresistive sensors (KMZ10B of Philips) were arranged to enable measurement of the magnetic field above the magnetised 3 cm wide steel strip (Fig. 7).

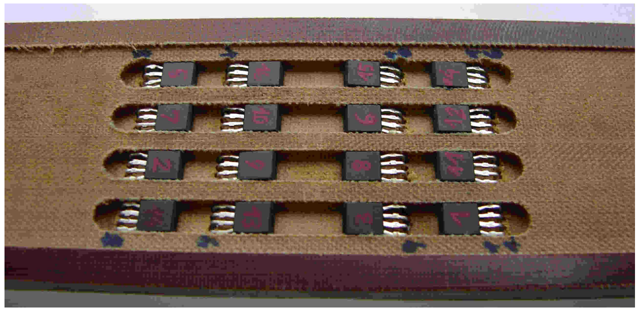


Fig. 5. The AMR sensors matrix designed for tests of magnetic field above the 3 cm steel strip

The transfer characteristic of typical KMZ10B sensor is presented in Fig. 6. The sensitivity (without additional gain) was about 50 mV/(kA:m). The sensor with active area of about 1 mm × 1 mm detects tangential component of the field (in the sensor plane).

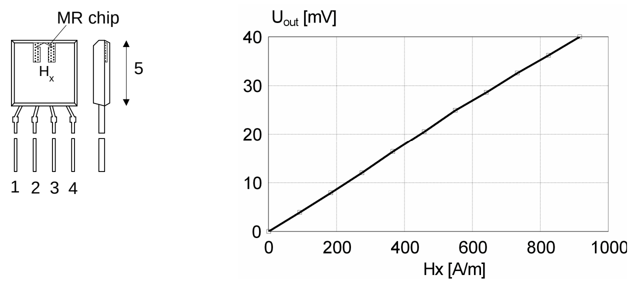


Fig. 6. The design and typical transfer characteristic of AMR KMZ10B sensor

The sensor matrix was designed to test the 3 cm wide steel strip in arrangement illustrated in Fig. 7.

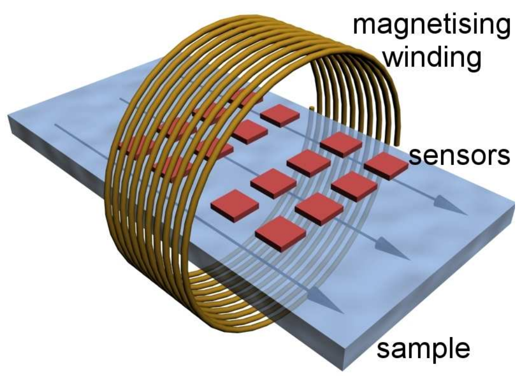


Fig. 7. The arrangement of the sensor matrix for testing of electrical steel strip magnetised by the magnetic field generated by the coil

The sensor matrix was developed for three main purposes:

a) for test the steel strip in $n \times 16$ points

b) for increase of the sensor output signal and to obtain the averaging effect

c) for improve of the speed of the scanning device.

4.1 The multipoint testing of electrical steel

The electrical steel is magnetised heterogeneously, especially in the case of grain oriented steel. Therefore it is necessary to test the sample in many points to investigate the material homogeneity and/or to average these results for the whole sample. Figure 8 presents the example of tests the hysteresis curve in 16 points of the strip sample.

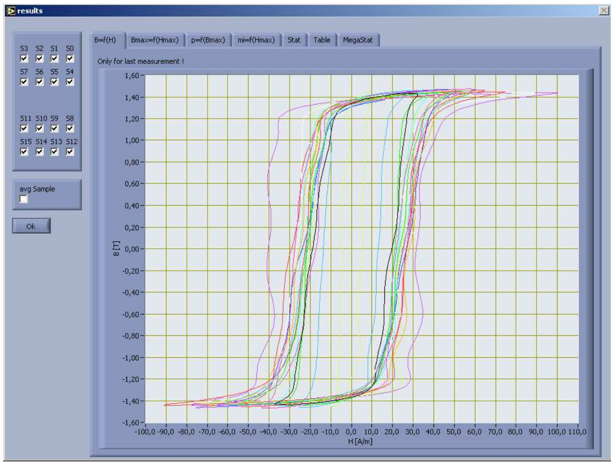


Fig. 8. The example of the results of testing the hysteresis curve in 16 points

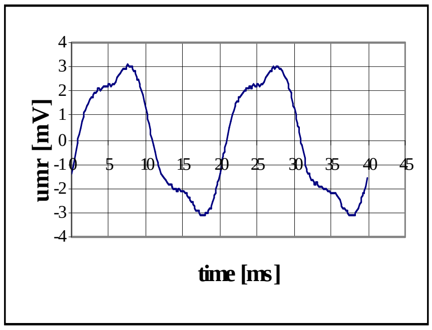
Fig. 9. The results of statistical analysis of the magnetic field strength in 64 points of the strip sample

In one cycle of measurement it is possible to obtain the results for 16 points (magnetising dependence $B=f(H)$, hysteresis curve, losses etc). But by simply movement of the sample (for example every 0.5 mm) it is possible to multiply the number of investigated points. Next after averaging we can obtain the result of investigation very near to the result obtained for one large sensor. Moreover we can also perform the statistical calculations to determine the material homogeneity. Figure 9 presents the results of investigations of the sample in 64 points.

4.2. Amplification and averaging of the sensor signal

Typically the AMR sensor output signal is rather small (not larger than 40 mV). Taking into account the sensitivity the AMR sensor signal is much better for magnetic field investigations than the H-coil sensor (in this case the output signal is less than 1 mV), but it would be very convenient to obtain much larger signal with better SNR ratio. By simply connecting in series the output signals of every sensors we can have the output signal in the volt range. Figure 10b presents the output signal of the whole matrix.

a)



b)

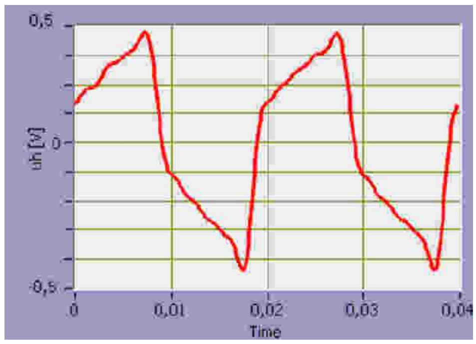


Fig. 10. The typical output signal of one AMR sensor (a) and the 16 sensors array - with connection in series all sensors (b)

The connection of all sensors of the matrix is also advantageous from other point of view. In some cases locally (on the area of about 1 mm^2) measurement of magnetic field strength is profitable. But when we test the whole sample it is drawback (in comparison with large coil sensor). We can of course average the result numerically (as it is described in Section 4a) but connection in series gives the same averaging effect more obviously.

Connection in series of all sensors is slightly difficult because in this case we have to supply every sensor with the sources galvanically isolated. In our case we constructed 16 supply sources with small transformers, but for larger number of sensors it would be inconvenient.

4.3 Improve of the speed of the scanning device

We designed the Magnetovision system [2, 3] for scanning and imaging of the magnetic field. Among other this system is used for test of material heterogeneity and structure. Fig. 11 presents the example of the result of scanning of the magnetic field above typical grain-oriented steel sample (magnetised to about 1.5 T).

a)

b)

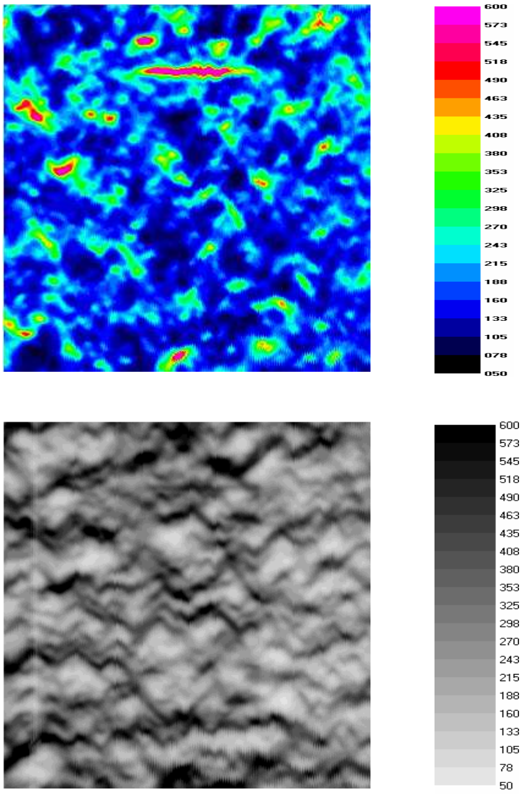


Fig. 11. The picture of magnetic field distribution above the grain-oriented steel sample: a) in form of a colour map, b) as black/white map

Usually we present the results of scanning in form of a colour map (Fig. 11a), that pretty well express the material heterogeneity. For editorial purposes we convert the same map to the black/white scale. Surprisingly such picture much better express the grain structure (Fig. 11b). Especially such structure is well expressed in the case of the steel with large grains, as it is demonstrated in Fig. 12.

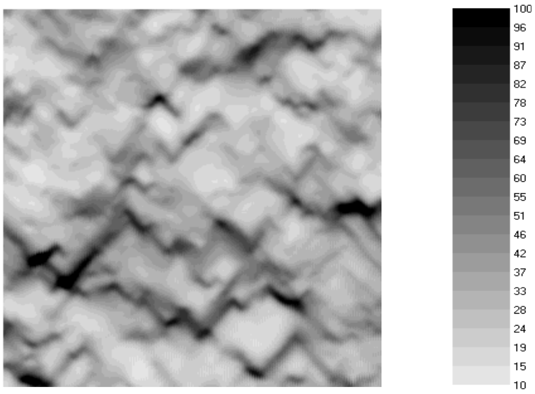


Fig. 12. The picture of magnetic field distribution above the HiB grain oriented steel

To obtain reliable and valuable results of investigations the tested sample should be sufficiently large. Typically we test the area 20×20 cm. The scanning process of such large area (with the scanning step 0.5 mm) requires the time of about one hour. By substitution of one sensor by the matrix of 16 sensors we simply decrease of the scanning time 16-fold.

5 CONCLUSIONS

The magnetic sensor array (sensor matrix) is very convenient in many investigations of magnetic field distribution. Unfortunately in comparison with the light sensors (for example CCD arrays) the magnetic sensor arrays are still seldom used. Promising is the development of GMR technology realised by NVE. To date researchers have to design and construct such sensor array by themselves, what sometimes is advantageous, because it is easier to adapt the device to the need. The paper presents examples of magnetic sensor arrays and applications of AMR sensor array to investigations of electrical steel.

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Received 28 November 2006

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