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Scanning of Magnetic Field as a Method of Investigations of the Structure of Magnetic Materials

Streszczenie. *Zaprezentowano system pomiarowy zaprojektowany do skanowania pola magnetycznego w przestrzeni trójwymiarowej. Jako czujnika pola magnetycznego użyto cienkowarstwowy czujniki magnetorezystancyjny AMR. Po przeprowadzeniu skanowania rozkład pola magnetycznego może być przedstawiany w postaci mapy. Wykazano, że mapa taka dobrze odwzorowuje strukturę ziarnistą materiału. Od struktury ziarnistej zależą parametry użytkowe materiału, na przykład straty w przypadku blach elektrotechnicznych. Badania struktury mogą być dobrym narzędziem do kontroli procesu technologicznego wytwarzania materiałów magnetycznych, a także nieniszczących metod defektoskopii. (**Skanowanie pola magnetycznego jako metoda badania struktury materiałów magnetycznych**).*

Abstract. *The measuring system designer for 3D magnetic field scanning is presented. As a sensor of magnetic field AMR magnetoresistive sensor has been used. The result of scanning can be presented in form o a colour map. Such map very well represents the grain structure of a material. This grain structure influences performances of the material, for example losses in the case of electrical steel. Investigations of the structure can be an useful tool for control of technology of magnetic material manufacturing as well as a non-destructive testing of material.*

Keywords: scanning of magnetic field, magnetic field imaging, grain structure, losses, non-destructive testing of material NDT.
Słowa kluczowe: skanowanie pola magnetycznego, struktura ziarnista, straty, nieniszczące badania materiałów, defektoskopia.

Introduction

Various systems designed for scanning of magnetic fields have been reported – for example Magscan system using Hall sensors [1] or Scanning Microscope [2] using also small Hall sensor. At Warsaw University of Technology was developed scanning system using small AMR (Anisotropic Magnetoresistive) sensor [3,4]. This system called Magnetovision [5,6] was used, among other, for testing of electrical steel quality [7].

The map of magnetic field scanned above the magnetized material can be used as the information about its structure. The properties of magnetic materials strongly depends on their grain structure, expressed as texture, anisotropy, losses. Therefore the investigations of these features are especially important for manufactures of magnetic materials.

The paper presents the examples of investigations of magnetic field scanned above the magnetic materials. These results can be used as a source of information about the properties of such materials.

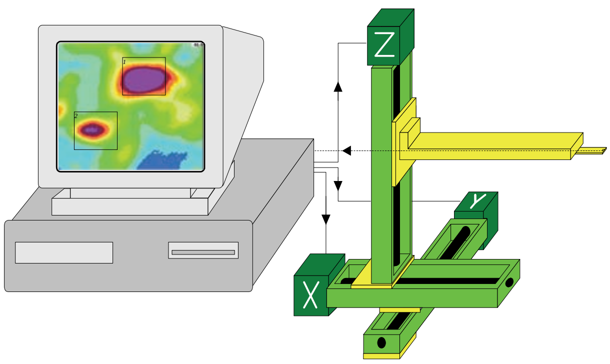


Fig. 1. An example of the scanning system for magnetic field investigations

The magnetovision system

In the Magnetovision system the sensor is moved above the investigated materials by using three stepper motors (Fig.1). As the sensor the AMR sensor KMZ10B of Philips with sensitivity of about 50 mV/(kA/m) and active area of about 1 mm^2 is most frequently used, because its performances suits very well for typical problems of investigation of magnetic materials. Various step of the movement (resolution) can be chosen but taking into account the dimensions of the sensor the best results are obtained for the step equal to 0.5 mm. It is important that thin film magnetoresistive sensors are sensitive to the magnetic field in their plane, therefore it is possible to investigate the tangential component of magnetic field.

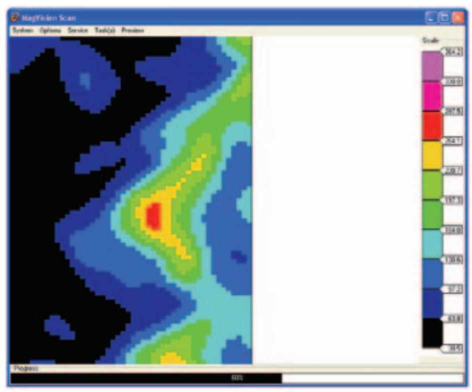


Fig. 2. The example of the map of magnetic field presented on the screen during the scanning process

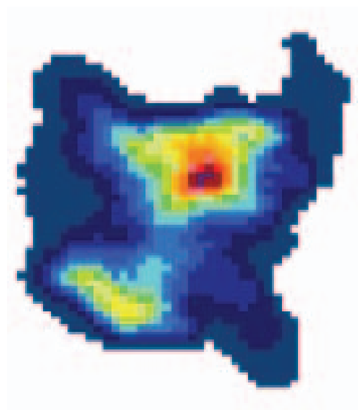


Fig. 3. The example of the map of magnetic field after finishing the scanning process

Appropriate software enables to observe the process of scanning – the map of magnetic field distribution is presented in on-line mode (Fig.2). After the scanning process every measured data is represented by colour area on the screen (Fig.3). The quality of such map depends on the resolution of scanning, but generally it is recommended to improve the map by processig the data using the interpolation techniques. As result of image processing on the screen is presented the map with areas representing the same value of magnetic field (Fig.4a).

a)

b)

c)

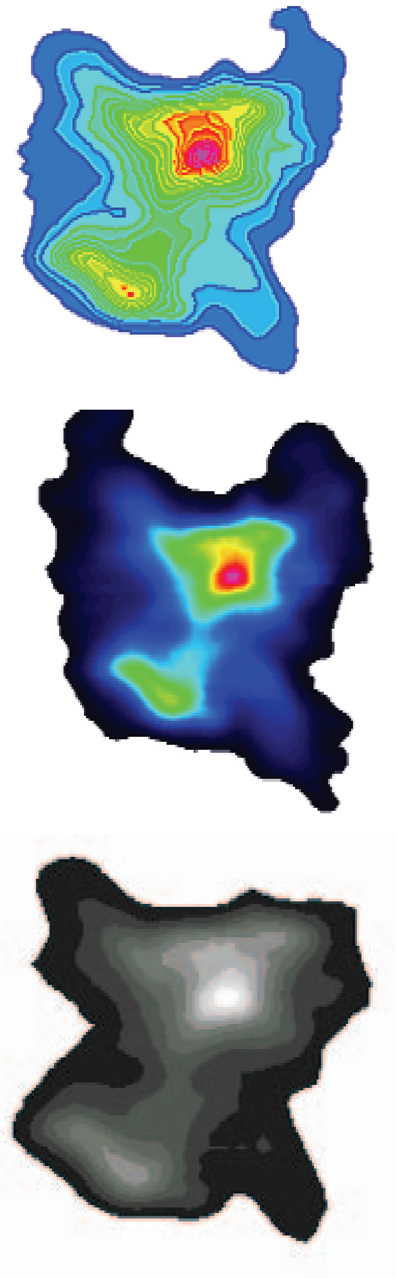


Fig. 4. The same map obtained as result of post-processing of measured data: a) with 20-colour scale, b) with 500-colour scale (photo quality), c) with gray scale

Depending on the used colour scale it is possible to obtained various quality of image (Fig.4). Figure 5 shows the final result of data processing, where beside the map it is also presented the value of magnetic field in selected line (or point). Very helpful is also histogram with information about distribution of magnetic field in selected line or area (min/max values, average value, standard deviation etc).

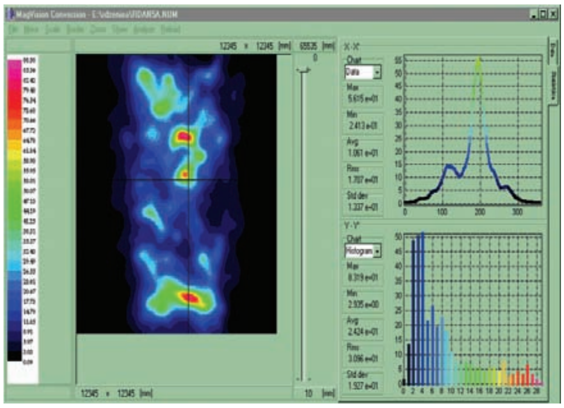


Fig. 5. The example of final result of processing the scanned data

a)

b)

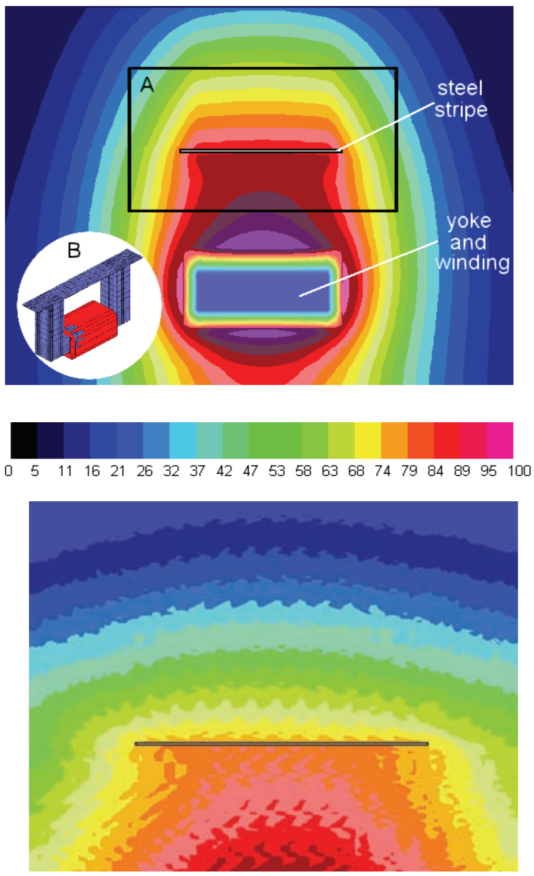


Fig.6. Distribution of magnetic field above the strip of electrical steel magnetized by c-yoke system (B – on upper figure): a) result of 3D magnetic field computation (theory), b) result of scanning (experiment) on selected area (A – on upper figure).

The map of magnetic field and the material homogeneity (quality)

Figure 6 presents the comparison of the result of computation of magnetic field distribution and the result of experiment (scanning). It was tested the magnetic field above the 3 cm wide strip made from non-oriented electrical steel and magnetized by c-yoke system. Because non-oriented steel with very small grains structure can be assumed as uniform one the correspondence between theoretical and experimental results is very good.

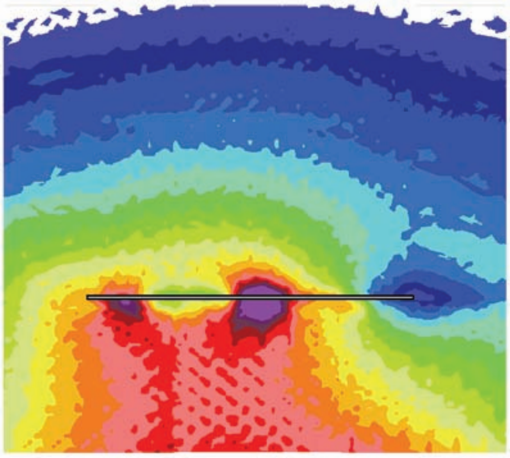


Fig.7. The same experiment as presented in Fig. 6b but with the sample from grain-oriented steel

The same experiment was repeated with the sample prepared from grain-oriented steel (Fig.7). Due to relatively large grains this material is heterogeneous one. This non-uniformity strongly influences the distribution of magnetic field around the sample.

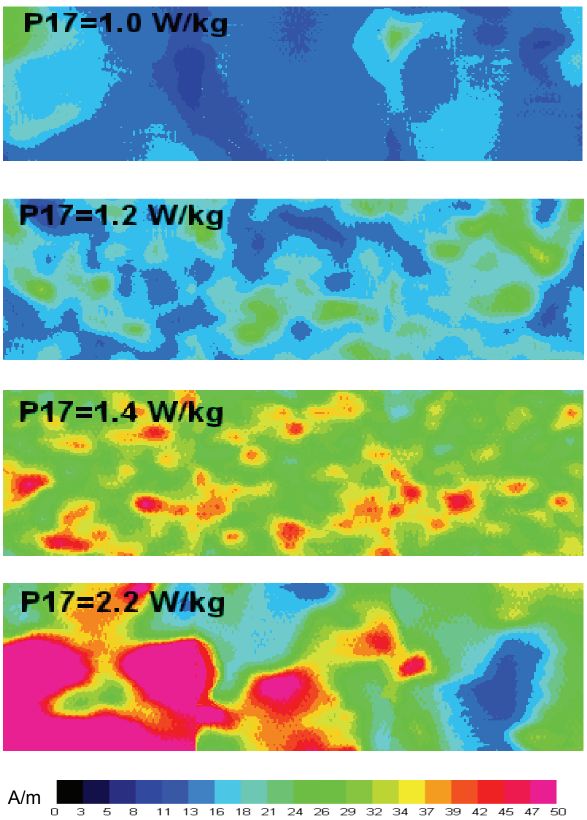


Fig. 8. The relation between the losses of grain oriented steel and the map of magnetic field above the sample (P17 – losses determined for the flux density B – 1.7 T)

The quality of grain oriented steel depends on the material heterogeneity. This quality is commonly described by losses. Fig. 8 presents four examples of map of magnetic field determined for the samples with various losses (determined using Epstein method). It is clear that the map brings immediately valuable information about steel quality – as more “cold” colours as better the steel.

a)

b)

c)

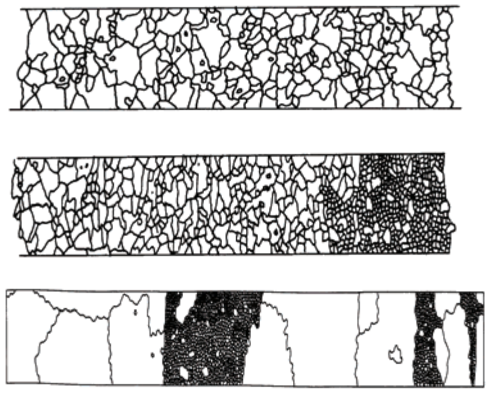
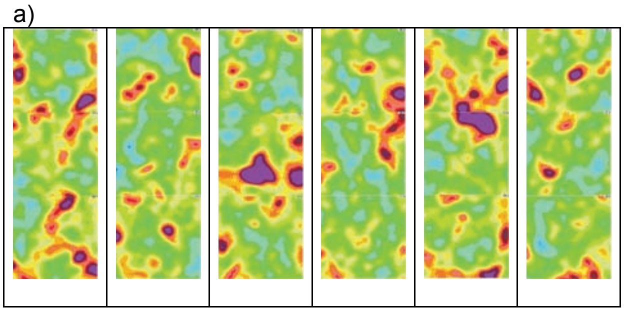


Fig. 9. The samples of grain oriented steel (3 cm strip): a) typical steel, b) steel with various grains, c) steel with extremely large grains separated by areas with very small grains (not completely crystallization process)

The map of magnetic field and the grain structure

The samples of various grain structure presented in Fig. 9 have been tested using the Magnetovision method. The results are presented in Fig. 10.

a)



b)

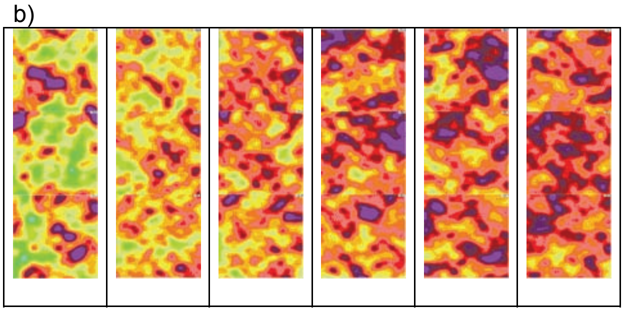


Fig. 10. The map of magnetic field above the sample with typical grains (a) and with gradual decreased grains (b)

Figure 11 presents the results of investigation of sample c) (from Fig. 9). In this sample the areas of extremely large grains are separated by defected areas (with not completely crystallization process). Such type of maps (Fig. 10 and Fig. 11) can help the manufacturer to control the technology.

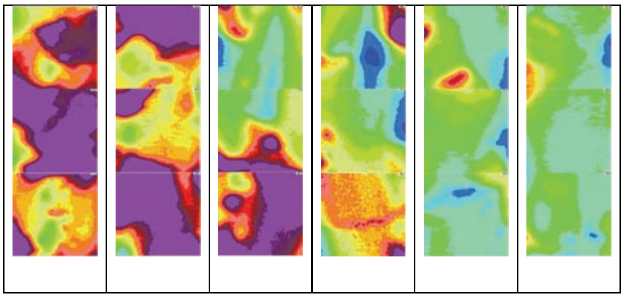


Fig. 11. The map of magnetic field above the sample presented in Fig. 9c

The scanning process is rather slow – the investigation of area 10 cm × 10 cm with resolution of 0.5 mm needs about one hour. Therefore the map can be substituted by the diagram describing the magnetic field distribution in one line. The examples of such diagrams related to the samples presented in Fig. 9 are shown in Fig. 12.

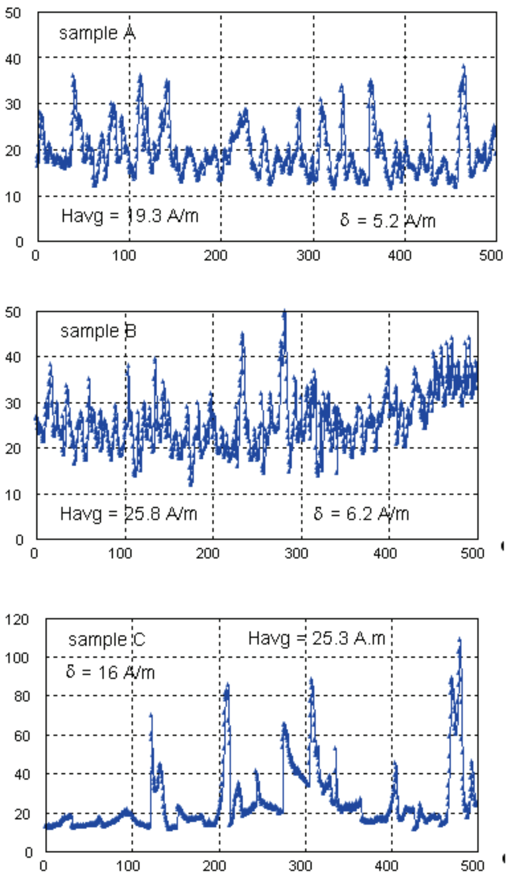


Fig. 11. Magnetic field distribution tested in one line above the samples presented in Fig. 9

Due to regular arrangement of the grain (due to the texture) the curves presented in fig. 11 should exhibit periodic character. Therefore it is possible to use the Fourier transform to analyze the period of oscillations. Fig. 12 presents two examples of such analysis. In the case of the sample with smaller grains (sample B) there are visible spectral lines representing period smaller than 5 mm. Thus the Fourier analysis helps in determination of the size of grains.

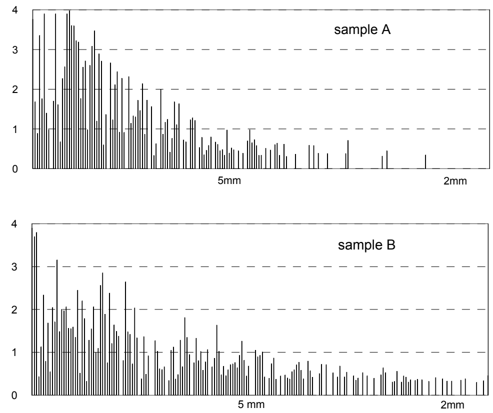


Fig. 12. The Fourier spectrum of the curves presented in Fig. 11 (vertical axis – percentage of the harmonic with respect to the average value, horizontal axis – period calculated as the distance 500 mm divided by number of periods)

The imaging of magnetic field distribution above the grain oriented samples

Usually it is convenient to present the distribution of magnetic field above the sample in form of a colour map. An example of such map determined for the sheet prepared from grain oriented steel is presented in Fig. 13a.

a)

b)

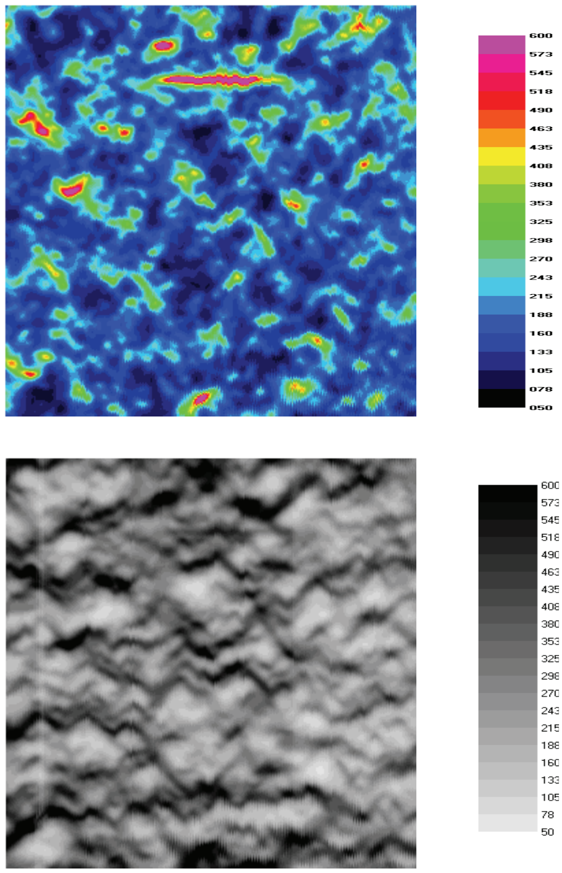


Fig. 13. The map of magnetic field distribution of the same sheet sample (tested area 10 cm × 10 cm) prepared as a colour map (a) and as the gray scale picture (b)

Sometimes (for example due to editorial requirements) it is necessary to prepare the map as a black/white picture. An example of such map is presented in Fig. 13b. Surprisingly gray scale picture much better express the grain structure. Especially such structure is well visible in the case of the steel with large grains, as it is demonstrated in Fig. 14.

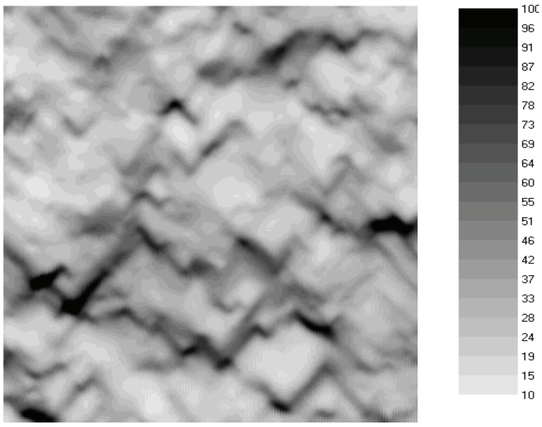


Fig. 14. The picture of magnetic field distribution above the HiB grain oriented steel

Another way to present the magnetic field distribution can be the 3D plot presented in Fig. 15. This plot was created as the result of 15 movements of the sensor across the rolling direction. These movements were distanced by 2 cm (thus the tested area was 30 cm × 50 cm).

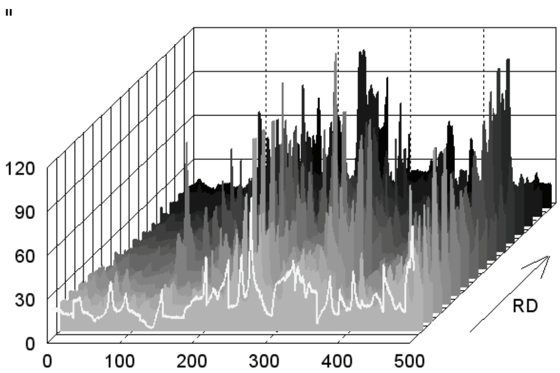


Fig. 15. The distribution of the magnetic field strength above the steel sheet

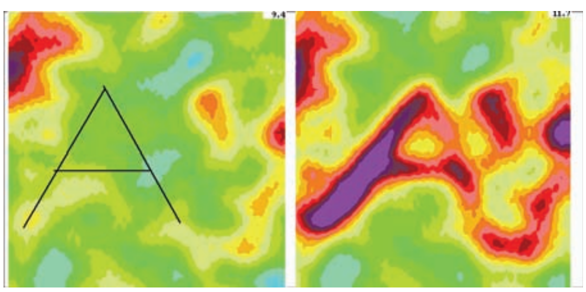


Fig. 16. The magnetic field above the steel sheet before and after writing a letter “A”

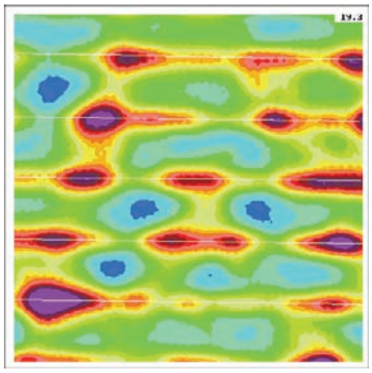


Fig. 17. The map of magnetic field above the steel sheet after “laser scribing”

The scanning results as a tool of NDT

In the maps presented above it is relatively easy to detect the areas with significantly deterioration of the performances (represented by locally increased magnetic field value). Thus by scanning of magnetic field it is possible to perform the non-destructive testing (NDT) of the material [8]. Fig. 16 presents the maps of the same area of steel sheet before and after writing the letter “A” with ball-point pen. These results of investigations demonstrate that typical electrical steel is very sensitive to stresses. It also proved that by mapping of magnetic field we can identify defects.

Conclusion

It is rather difficult to answer what really represents the result of scanning of magnetic field distribution above the magnetized material. Figure 17 presents the results of investigations of a steel sheet after technological process called “laser scribing”. It is known that laser scribing improves (changes) the domain structure. Thus we can conclude that the magnetic field distribution represents rather complex state of magnetized material (depending on grain and domain structure). This state of magnetization can be used to test the structure of magnetic materials. Presented in this paper results of experiments proved that such investigations can be used for assessment of losses (steel quality), grain structure and/or defects.

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