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ANALYSIS OF HETEROGENEITY OF ELECTRICAL STEEL

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The paper presents the methods of analysis magnetic field strength distribution above magnetized electrical steel: scanning method, sensors array or measuring magnetic field strength along one line. Various methods of analysis of obtained results are discussed: statistical analysis, digital signal processing – FFT analysis, digital image processing - pattern recognition methods or morphology based operations.

Keywords: electrical steel, material evaluation, steel homogeneity, scanning of magnetic field

1 INTRODUCTION

The map of magnetic field distribution above magnetized electrical steel can be an useful tool for evaluation of steel quality [1,2]. Electrical steel, especially grain-oriented steel is heterogeneous. This heterogeneity results from the grain structure of the steel and various directions of crystallographic axes of individual grains (texture). Exist also second kind of heterogeneity resulting form the quality of technology – for example not complete crystallisation/recrystallisation process or presence of impurities. Knowledge about both kinds of heterogeneity can be important factor for steel manufacturers helpful in improvement of technology and finally quality of electrical steel.

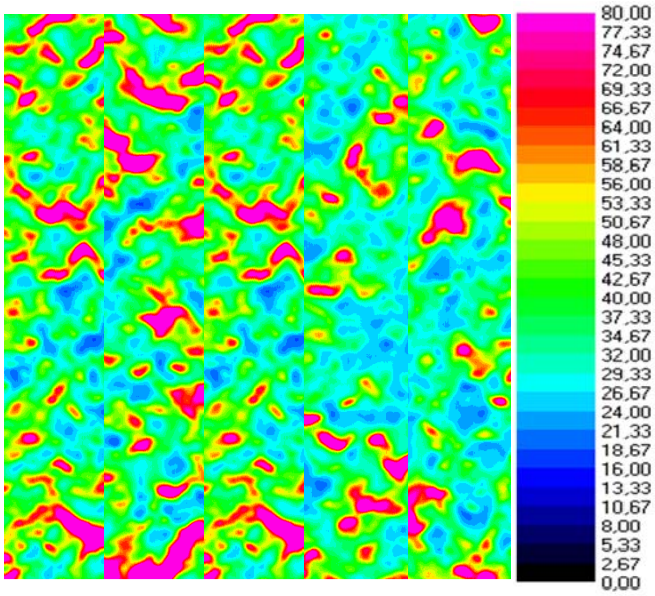

Fig. 1. Example of results of scanning of magnetic field above 5 strips of grain oriented steel (B = 1. 5 T)

Figure 1 presents the results of scanning of magnetic field above five adjacent Epstein strips (3 cm wide). Although steel was produced by reputable manufacturer the distribution of magnetic field non-uniform - what is obvious taking into account the grain structure. But what is more important we determine quite great differences between individual strips (what is not detectable using conventional steel testers). For example strip four is much better than strip two. Thus we can say that picture of field distribution can be graphical signature representing steel grad and quality.

Although results of scanning are very impressive we have difficulties to convince to this method steel manufacturers. They pointed following drawbacks of this method:

- sophisticated and time consuming procedure of testing,
- difficulties in fast and clear interpretation of the testing results.

That is why in this paper we present simplification methods of analysis of heterogeneity of electrical steel.

2 SENSOR ARRAY INSTEAD OF SCANNING DEVICE

For testing of uniformity of electrical steel we used two methods: the first one was the scanning of surface magnetic field strength H using small (1 mm^2 area) AMR sensor. This method called magnetovision is described elsewhere [3]. The step of the movement of the sensor can be very small (part of mm) and as result we obtain the colour map (and of course matrix of data) representing distribution of magnetic field strength.

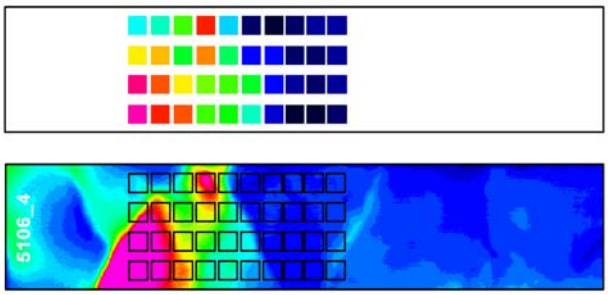

Fig. 2. The comparison of scanning results and results obtained using the array of the sensors

The drawback of this method is rather long time necessary to perform scanning (typically about one hour for the area 3 × 9 cm). Therefore we used second method -

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applying of the array of AMR sensors [4]. Using such sensor array it is possible to analyse of magnetic field distribution practically in real time mode but of course with significant deterioration of number of investigated points. Figure 2 presents the example of comparison of results obtained by both methods.

Substituting the scanning device by the array of sensors means significant shortening and simplifying of the test procedure. In the case of scanning we can only determine the distribution of magnetic field strength. Using the sensor array we can compute the distribution of other important steel parameters, as for example losses or permeability (Fig. 3).

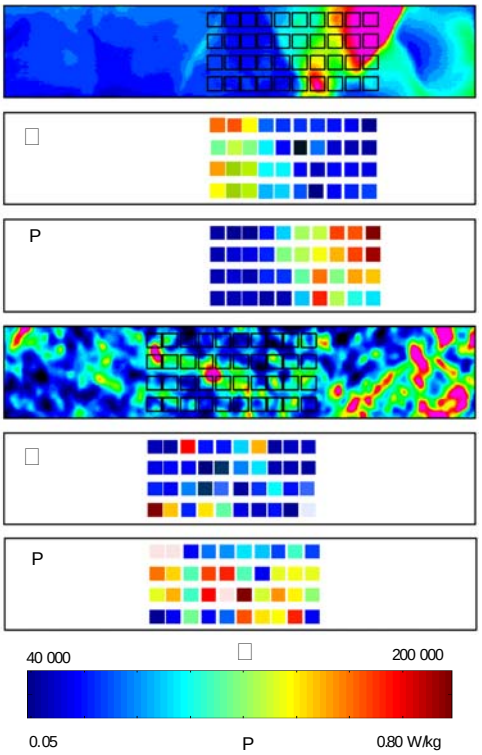

Fig. 3. The results of computation of surface distribution of losses and permeability in two kinds of samples – with extremely large grains (upper) and typical grains (bottom)

3 STATISTICAL ANALYSIS OF RESULTS OF TESTING

The simplest and most obvious is to use the statistical method for the analysis of the results of experiment. We can calculate the average value of the parameter and of course as smaller is average value of magnetic field strength for fixed value of flux density as better is tested steel.

Beside the average value we can calculate the standard deviation. The smaller standard deviation the better is the steel homogeneity. Very useful is also the presentation of testing results in form of histogram. Figure 4 presents an example of statistical analysis obtained using software designed for scanning device. It presents the results of statistical analysis calculated for selected line of the sample. For manufacturer more interesting can be the same results but calculating for the whole sample or even the set many samples. Figure 5 presents the example of statistical analysis of the result obtained from the array of the sensors.

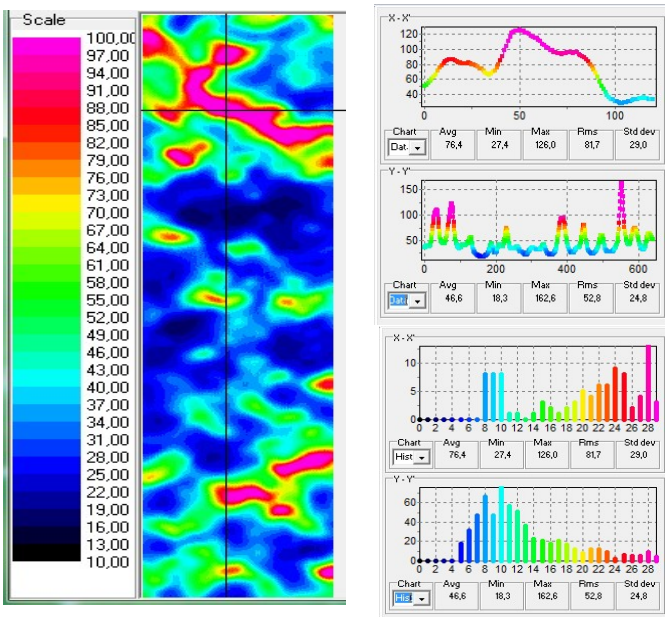

Fig. 4. The example of statistical analysis of the result of scanning

4 SPECTRAL ANALYSIS OF THE DISTRIBUTION OF MAGNETIC FIELD

For analysis we can select from the map one or several lines representing change of magnetic field strength. Figure 5 presents two examples of such plots representing samples with various grains (indicated by the frequency of the change of magnetic field strength).

Fig. 5. The example of statistical analysis of the results obtained from array of the sensors (upper – distribution of magnetic field strength, bottom – histogram)

It is relatively easy convert the line representing the change of magnetic field (Fig. 5) into the electrical signal applying for example Fast Fourier Transform or Wavelet Transform. The calculated spectrums representing sample from Fig. 5 are presented in Fig. 6.

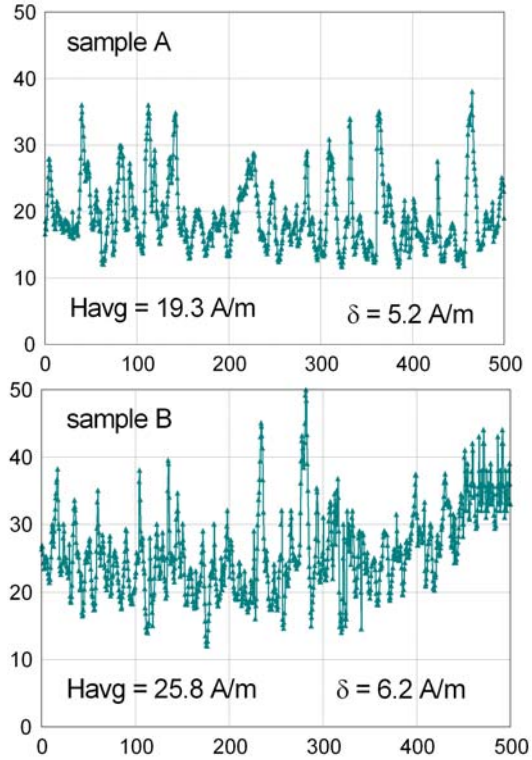

Fig. 6. Two examples of the change of magnetic field determined along one line of the sample

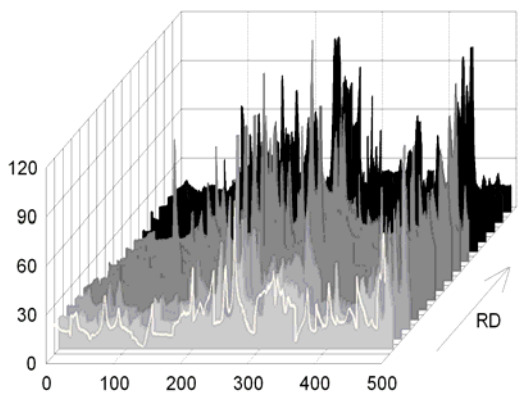

Fig. 8. The distribution of the magnetic field strength above the steel sheet

It is also possible to calculate two-dimensional Fourier Transform representing the whole area. Fig.7 presents the 3D plot of magnetic field distribution above the steel sheet (sample C). 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).

APPLYING OF THE PATTERN RECOGNITION OR MORPHOLOGY BASED OPERATIONS

The spectral or statistical analysis do not inform us about number typical (on exceptional) areas (grains). For example if we establish recommended type of local area of magnetic field we can look for number of such elementary areas.

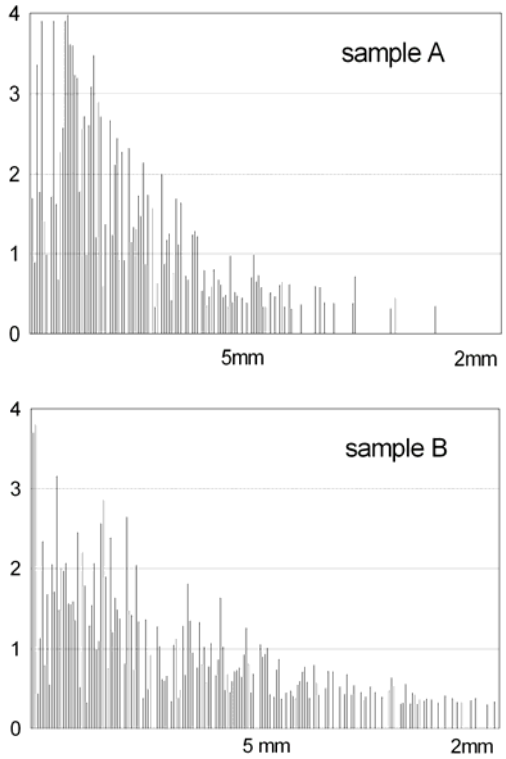

Fig. 7. The spectrum lines of the curves presented in Fig. 5 obtained using FFT

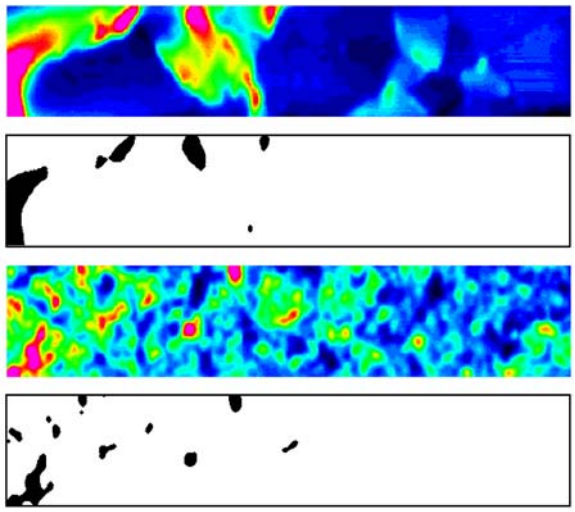

Fig. 9. The graphical selection of the areas with large value of magnetic field strength

Or we can look for areas with typical value or exceed recommended values. This type of analysis we can perform directly as digital image analysis. We can use pattern recognition methods or morphology based operations [5].

6 CONCLUSIONS

The map of distribution of magnetic field strength above magnetised electrical steel can be a valuable tool for assessment quality and heterogeneity of this steel, especially in the case of grain oriented steel.

We can simplify the time consuming scanning method using other testing device.

Fig. 8 presents an example of the graphical selection of the areas with value of magnetic field exceeding assumed value.

- substitute the scanning device by sensors array,
- instead of testing the whole area we can test the steel along one selected line.

We can simplify the analysis of obtained results using following methods:

- statistical method, especially by calculating mean value and standard deviation,
- digital signal processing - using FFT or Wavelet analysis,
- digital image processing, especially pattern recognition methods or morphology based operations.

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