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Material Edge Conditions of Electromagnetic Silicon Steel Sheets

***Abstract**. Material and magnetic degradation on the edges of electromagnetic silicon steel sheets is usually neglected in designing electro-mechanical equipment. Magnetic changes at the sheet edges are insignificantly small in the case of transformers. In the electric machines they can produce significant losses, amounting to 0.5 % when the losses due to the magneto-elastic and reverse phenomena (Joule and Villari) are taken into account. In this context the paper presents the results of laboratory and simulation studies of the influence of various production technologies on the material structure and magnetic properties at edges of elements for electro-mechanical devices. (**Materiałowe warunki brzegowe blach elektrotechnicznych krzemowych**).*

***Streszczenie.** Degradacja materiałowa i magnetyczna na krawędziach blach elektrotechnicznych stali krzemowych jest powszechnie pomijana podczas projektowania urządzeń elektromechanicznych. Zmiany magnetyczne materiału na krawędziach blach w znacznie mniejszym stopniu dotyczą transformatorów, w maszynach elektrycznych mogą powodować straty na poziomie ułamkowych części w skali jednego procenta. Dodając do tych strat wpływy zjawisk magnetosprężystych i odwrotnych (Joule'a i Villariego) można mówić już o stratach sięgających 0,5%. Wstępne badania laboratoryjne i symulacyjne dla nowoczesnych rozwiązań maszyn elektrycznych wskazują na istotność tego zagadnienia. W artykule opisano badania wpływu procesu przygotowania wykrojów uzyskanych w różnych technologiach na strukturę materiału.*

Keywords: magneto-elastic and elasto-magnetic effects, plastic strains, changes of magnetic parameters, changes of magnetic hysteresis loop of electromagnetic steel sheets.

Słowa kluczowe: efekty magneto-sprężyste i sprężysto-magnetyczne, odkształcenia plastyczne, zmiany parametrów magnetycznych, zmiany pętli histerezy magnetycznej blach elektrotechnicznych

Introduction

At the stage of designing electromagnetic devices it is often assumed that the magnetic parameters of material are constant, at most they can be conditional on temperature. Parameters of a ferromagnetic material depend largely on the mechanical stress and plastic strains. The magneto-elastic sensitivity of structural steel is low. Sensitivity of electromagnetic steel, especially of steel for transformer sheets, is high and cannot be neglected in electromagnetic discussion. Taking into consideration the impact zone of elastic stress and material changes stemming from assembly works, in figure 1 the temporary image of magnetic induction in engine cross-section is presented. Simulations were made using an engine model according to KOMEL [2] design. This is an engine characterized with low power, using N33SH neodymium magnets embedded in the rotor core, with three-phase stator winding powered with an inverter (fig. 1).

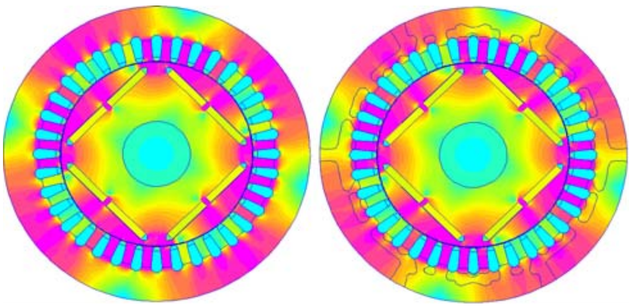


Fig. 1. Cross-section of an electric machine circuit

Laboratory studies of the changes of magnetic hysteresis loop caused by elastic stress and simulations of the magnetic induction distribution in a gap of the sector of magnetic circuit of the electric machine display significant differences [1, 2, 3]. Induction in the gap is similarly influenced by the technology used for producing rotor and stator.

Studies devoted to transformer sheet microstructure

The sample submitted for tests was a sector of the laser cut area, of the motor stator on which measurement points were chosen (fig. 2). A metallographic specimen was made from the sector which was later etched in 5% nital (fig. 3).

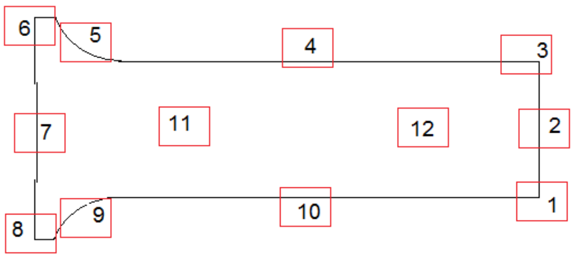


Fig. 2. Sector of a cutting

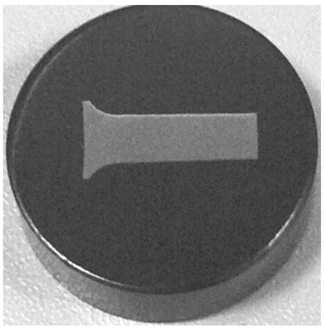
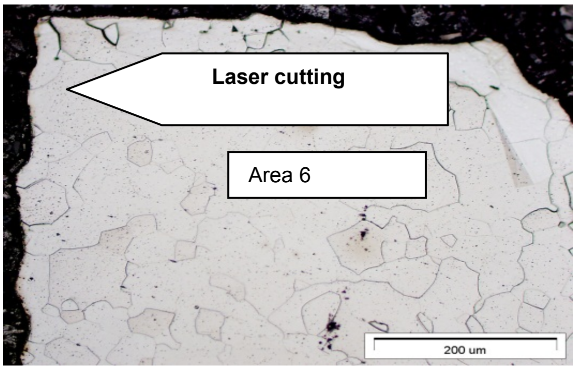
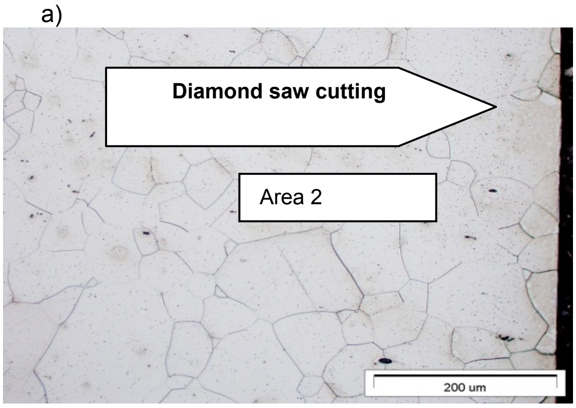


Fig. 3. Test sample

Microstructure studies were carried out using Olympus GX71 optical microscope in the light field with a magnification of 100 and 200x. Sample microstructure images were analysed in areas presented in figure 2. Microstructure of the transformer sheet is characterized with equiaxial ferrite grains, with scarce carbide separations both on the edges and inside the grains (fig. 4).



a)



b)

Fig. 4. Images of the structure on the laser cut edges (a) and diamond saw cut edges (b)

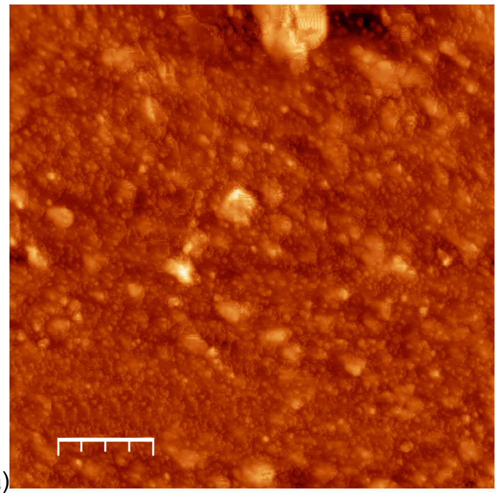
The visible edges created as a result of laser (area 6 – fig. 4a) and diamond saw cutting (area 2 – fig. 4b) with water cooling do not display any significant changes of structure grains. No microstructure deformities on the edges of the silicon steel sheet studied were detected when compared to its central part. Before further studies a micro X-ray analysis of the material was carried out. The micro X-ray analysis confirmed the chemical composition declared for the material used for studies.

Studies of magnetic properties of sample micro-zones. AFM / MFM microscope

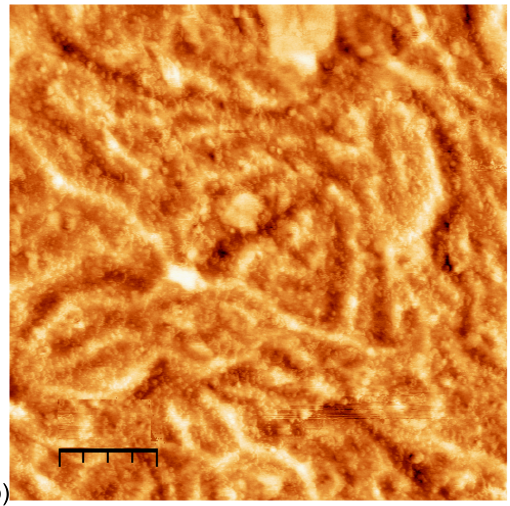
The primary objective of the studies initiated by the research centres of the Silesian University of Technology, Warsaw University of Technology and IPPT PAN was to determine the impact of the process of making silicon steel sheet cuttings for constructing electromagnetic machines and devices on the final product parameters, including but not limited to the energy conversion efficiency and the possibilities to use AFM and MFM techniques. The scope of studies presented is interesting for foreign academic centres with respect to optimized structure of low-power engines (automotive sector).

MFM (Magnetic Force Microscopy) analysis used for measurements results in magnetic force images in areas indicated in figure 2. Figure 5 (p.2000) presents images for zone four. Figure 5a presents a height of the area studied, while figure 5b an intermediate effect of surface magnetization (residual magnetism) measured via the microscope probe deflection and a change in their vibration phase [deg]. Those results present qualitative changes.

The measurement of magnetic interactions of the sample with the vibrating microscope probe is an indirect one and requires additional studies scaling the phase shift of the microscope probe in accordance with the magnetization parameter.



a)



b)

Fig. 5. Examples of MFM images (not scaled) for the measurement of unevenness (a) and magnetic interactions (b) of zone four

Evaluation of magnetization changes basing on height and angle image histograms

Images obtained from the measurement of frequency modulation degree (phase [deg]) of the vibrating lever of the microscope probe present magnetic domains of material in B_r state, depending on the magnetization of the surface studied caused by the geomagnetic field. Introducing external field increases the dimension of magnetic domains. Dark and light areas depict dimensions of magnetic domain walls. There are numerous methods to determine magnetization degree using domain size in an analytical way. In the study it was attempted to differentiate magnetic material by means of evaluating the level of residual magnetism B_r by means of image colour distribution. Histogram of the number of specific phase shift events for the magnetic interaction of the material with MFM probe is connected with image colour.

In figure 6 there are histograms for images shown in figure 5 (p2000), while figure 7 depicts several functions for obtained histograms.

Unevenness histograms further indicate the quality of sample preparation. For sample p1000 they reveal that the metallographic specimen was not prepared using uniform techniques, but by means of combining several specimen treatment methods - the sample centre (fig. 2). In addition, they reveal significant surface unevenness between the sample centre and its edges (p1002).

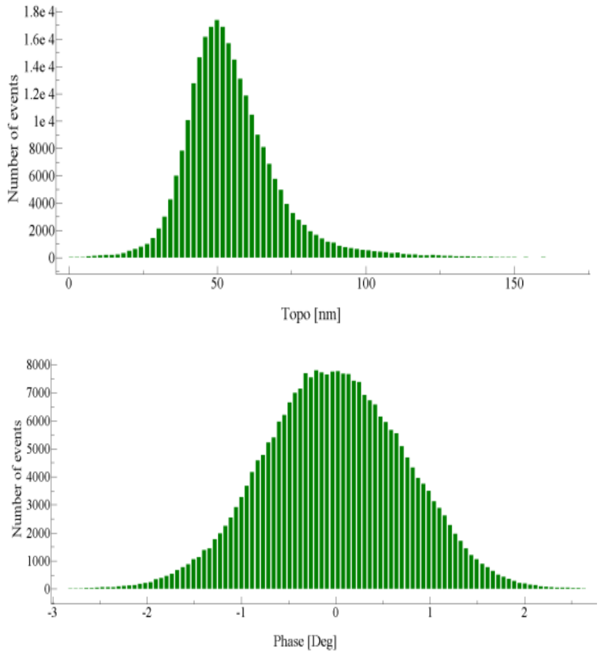


Fig. 6. Height and phase shift histograms for the sector studied

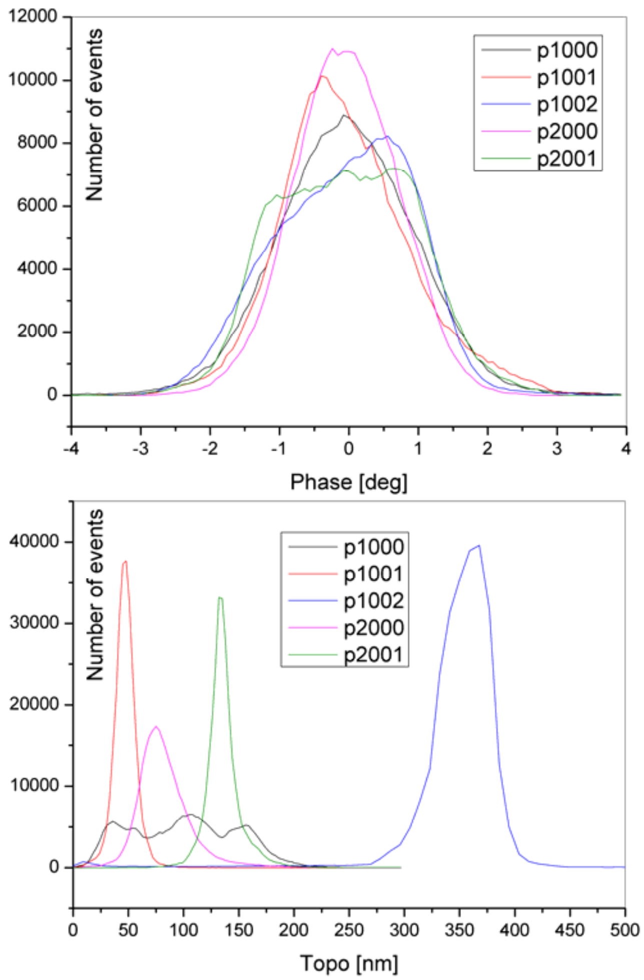


Fig. 7. Comparison of selected histograms

The unevenness errors have no significant influence on the magnetic test results. Local unevenness changes (fig. 5) determine the shape of the magnetic domain.

Material studies using BEMI

The structure study method by means of BEMI, characterizing material fatigue, shall be presented using the example of steel bands of a railway motor wheels. The magnetic changes for the band steel were measured using BEMI (**B**arkhausen Noise and **E**ddy Current **MI**croscope – fig. 8).

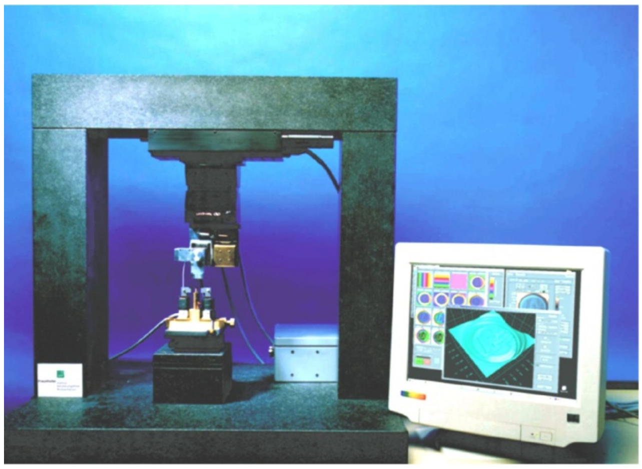


Fig. 8. BEMI illustration

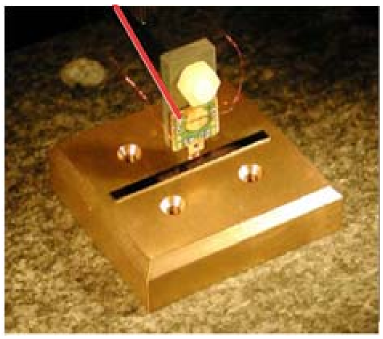


Fig. 9. Sample of microscope BEMI head mounting solution

Material taken from a new and a used band sample was compared simultaneously. BEMI enables to obtain results by scanning the surface with a micrometric accuracy, using the head shown in figure 9.

The BEMI station was made by employees from a magnetic unit of Fraunhofer Institute (IZFP) [6].

The universal character of BEMI station stems from a classic structure of the double-coil magneto-inductive head. One winding is inductive, the other measuring. While measuring Barkhausen noise, both coils provide measuring voltages from the surface of the component magnetized with external magnetic field. Examples of the results for scanning sample surface (fig. 10) for an eddy current head are presented in figure 11.

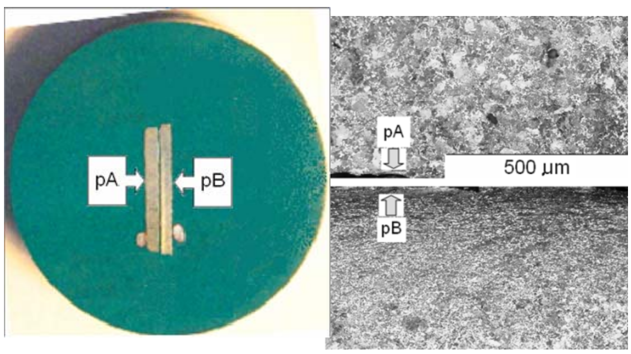


Fig. 10. Metallographic specimen and material structure

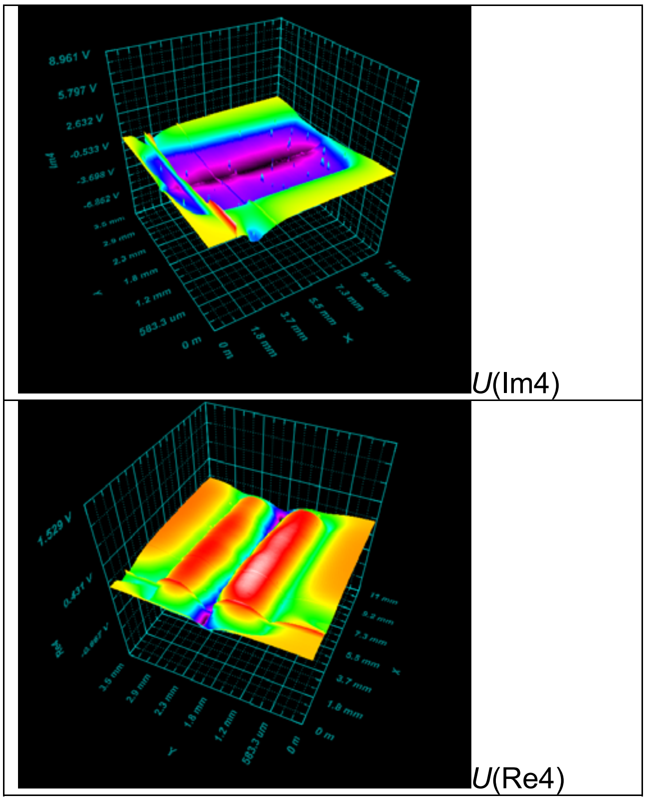


Fig. 11. Images of imaginary and real components of the eddy current probe voltage

The differentiation between the degradation levels was possible starting from the frequency of 1.5 MHz. The method proves to be useful for evaluating material surface or its degradation in a millimetre scales.

Conclusions

The preliminary results presented prove that the problem is really significant. All the same, they open wide perspectives of studying complex magneto-mechanical issues. Such studies are of an multi- and inter-disciplinary nature. They necessitate uniform methods of preparing samples and metallographic specimens, as well as calibrating magnetic measurements. During subsequent stages, simulations and laboratory tests will be required. In the context of rapid material evaluation due to the changes of magnetic infiltration or electric conductivity the chances offered by BEMI were presented.

Researches in the above area are also conducted by scientific centres in Wrocław and Katowice [7, 8, 9].

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