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INFLUENCE OF MAGNETIZING FREQUENCY AND MEASURED DATA PROCESSING ON BARKHAUSEN NOISE PARAMETERS OF NON-ORIENTED FeSi STEEL

Jozef Paľa – Jan Bydžovský

In this paper we investigated the influence of the magnetizing frequency on the determination of the Barkhausen noise (BN) parameters for the correlation with material properties (grain size) of non-oriented FeSi steel. Measurement results showed that changing frequency of the magnetizing field significantly influences the measured signal from the sensor picking up the BN. Increasing frequency causes the rise of the low frequency electromotive force (EMF) signal which mixes with the BN and thus influences the measurement accuracy. At highest investigated frequency of 10 Hz the EMF signal is so high that it is problematic to remove it without affecting the BN. We studied also the effect of different types of sensors on the BN and the low frequency EMF signal.

Keywords: Barkhausen noise, magnetizing frequency, grain size, FeSi steel

1 INTRODUCTION

In order to produce a high quality soft magnetic material (FeSi steel), it is important to control the microstructure of steels in terms of grain size, crystallographic texture and homogeneity. One of the non-destructive methods used to evaluation of the quality of steels is the Barkhausen noise (BN) analysis [1, 2]. The BN yields statistical information about magnetization process in ferromagnetic materials at a slowly changing applied magnetic field. Because it originates from discontinuous movements of domain walls, it reflects the interaction of domain walls with pinning centers at grain boundaries, dislocations, inclusions and precipitates. The dependence of different parameters of the BN on grain size in Fe-(3%)Si sheets or (low) carbon steels has been analysed in many papers [1-5]. The combined influence of sample preparation conditions and average grain size on the BN parameters is rather differently interpreted [5] and it has not been fully explained whether the discrepancy between measurement results of various authors is caused by different material properties, different measurement conditions or something other. In this paper we investigated the influence of different magnetizing frequencies, different sensing methods/sensors on the BN in our measurement system and we tried to explain the influence of the frequency spectrum of the BN on the correlation between the BN and the grain size of non-oriented FeSi steel.

2 EXPERIMENTAL

The investigated material was non-oriented steel with different grain sizes achieved using various combinations of annealing temperatures and rolling reductions of FeSi sheets. We obtained the samples of dimensions 0.5 mm x 10 mm x 40 mm with the grain sizes of 28, 46, 70, and 150 μm [5].

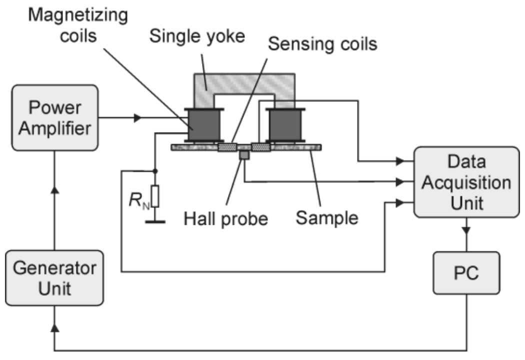

Fig. 1. Measuring set-up with two encircling sensing coils

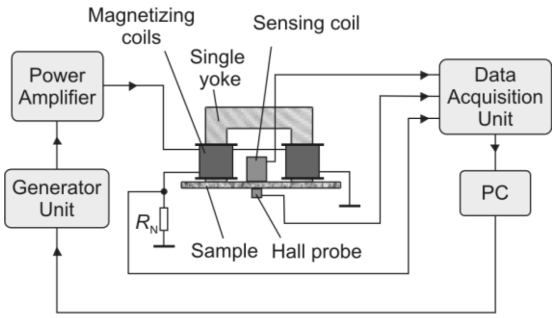

Fig. 2. Measuring set-up with the perpendicular sensing coil

For the purpose of the analysis of the influence of the magnetizing frequency, the magnetic properties were measured at the sine magnetic field intensity with magnetizing frequencies from 0.1 to 10 Hz. Used measuring single yoke system was made in two versions of sensing coils (Figs. 1, 2). The magnetizing coils were wound on the yoke legs made from low carbon steel. The magnetic field intensity was measured by a Hall probe placed below the sample. The BN was measured by two 200 turns coils connected in series opposition and wound around the sample (Fig. 1), as well as by a perpendicular sensing coil with 2000 turns of wire wound around magnetically soft amorphous ribbons with overall dimensions 1 mm x 2 mm x 15 mm (Fig. 2). The signal

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from these sensors was amplified by the amplifier and second-order low-pass filter SR560 with the cut-off frequency of 100 kHz and then fed to the data acquisition card. If otherwise not stated, the low frequency electromotive force (EMF) signal was obtained from the sensor signal in the processing software using a digital fifth-order Butterworth low-pass filter with the cut-off frequency 100 times higher than the magnetizing frequency, and the BN was separated from the sensor signal by a digital fifth-order Butterworth high-pass filter with the same cut-off frequency.

3 RESULTS AND DISCUSSION

To investigate the dependence of the BN on the magnetization state, we calculated envelopes of the BN. Every point of the BN envelope was obtained as the root mean square of 2000 adjacent points of the BN.

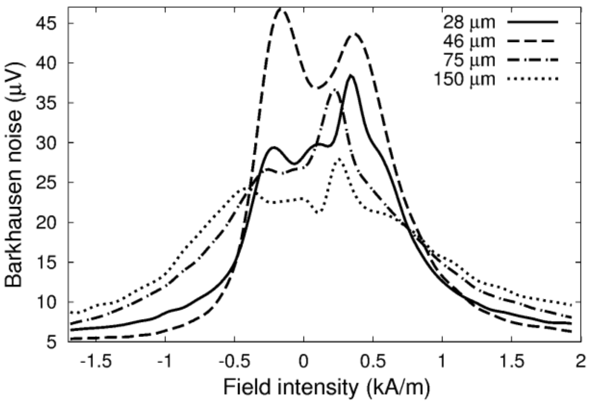

Fig. 3. The BN envelopes for samples with different grain sizes at the magnetizing frequency of 0.1 Hz

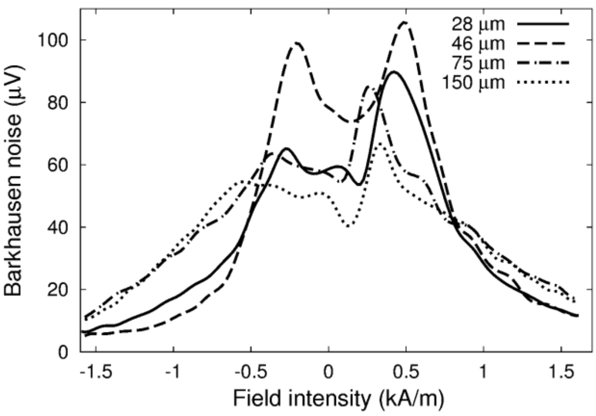

Fig. 4. The BN envelopes for samples with different grain sizes at the magnetizing frequency of 1 Hz

Figs. 3-5 show envelopes of the BN for magnetizing frequencies 0.1, 1, and 10 Hz. Higher frequencies of the magnetizing field in general brings some advantages compared to smaller ones, such as a higher magnitude of the BN and thus a higher signal-to-noise ratio, faster measurement, smaller number of acquired sample points at the same sampling frequency etc. However, raising the magnetizing frequency has also some disadvantages, especially it raises the problem with the low frequency EMF signal, which mixes with the BN.

By analysing the BN we can obtain valuable information about the influence of structural defects and grain boundaries on magnetization process and thus also information about the quality of the material. Up to now analyses [1-8] did not give clear answer about the influence of the grain size of steels, what can be caused by different measurement conditions. As we can see ion Figs. 3-5, in our case the BN increases with the magnetizing frequency and the character of the dependence of the BN on the grain size is similar for all frequencies. However, the change of the BN with the grain size decreases with the magnetizing frequency.

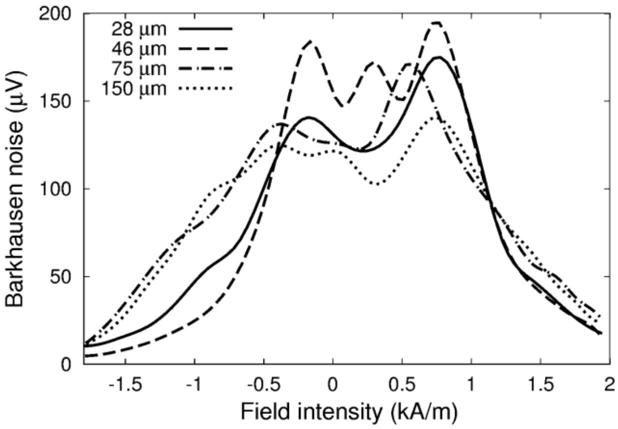

Fig. 5. The BN envelopes for samples with different grain sizes at the magnetizing frequency of 10 Hz

Further, the experimental results indicated significant impact of the EMF signal on the envelope of the BN. To suppress this EMF signal, several techniques are used, mainly utilizing two sensing coils connected in series opposition or using perpendicular sensing coil. First, we analysed the impact of the magnetizing frequency on the residual EMF signal and its interference with the BN for two coils connected in series opposition, which were used as a sensor in our previous measurements. Connection of both sensing coils in series opposition causes, that two similar EMF signals from both sensing coils are subtracted and only the BN should be in the sensor output. But since the construction and the arrangement of both sensing coils are not the same in practice, non-zero residual EMF signal results at the sensor output, what complicates the evaluation of measured data.

Example of the residual EMF signal is shown in Fig. 6. This residual EMF signal is very non-sinusoidal and therefore it has harmonics components reaching frequencies much higher than the magnetizing frequency. These harmonics components mix with the BN and so influence results of measurements. Even when we use a high-pass filter with the cut-off frequency 100 times higher than the value of the magnetizing frequency, we do not suppress this residual EMF signal completely.

Dependence of the peak-to-peak value of the residual EMF signal on the magnetizing frequency for the selected sample with the grain size of 28 μm is shown in Fig. 7.

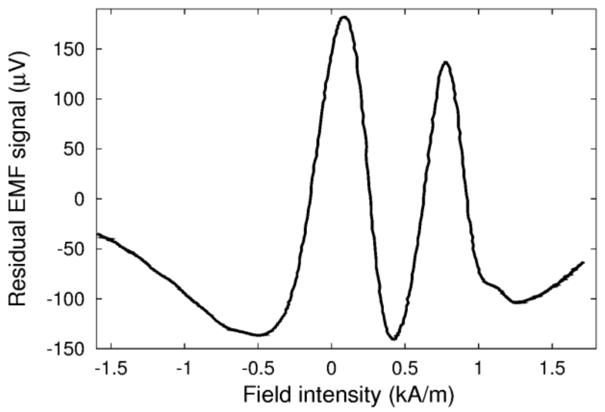

Fig. 6. Example of the residual EMF signal for the sample with the grain size of 28 μm and the magnetizing frequency of 1 Hz

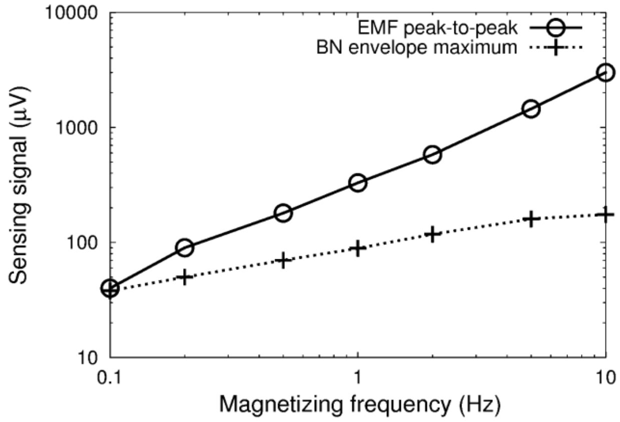

Fig. 7. The peak-to-peak value of the residual EMF signal and the amplitude of the BN envelope as functions of the magnetizing frequency for the sample with the grain size of 28 μm

From this figure it follows that even at the lowest frequency of 0.1 Hz the residual EMF signal is comparable with the amplitude of the BN and cannot be neglected. The magnitude of this signal increases almost proportionally with the magnetizing frequency, since it obeys the Faraday law. Thus it rises approximately ten times after the change of the magnetizing frequency from 1 Hz to 10 Hz. On the other side, the amplitude of the BN raises only about two times with this change of the magnetizing frequency, since the BN jumps are not so influenced by the magnetizing frequency. The increase of the BN causes mainly overlapping of the BN jumps in time. From this it appears that with raising the magnetizing frequency the impact of the residual EMF signal on the BN should increase and that at highest evaluated frequencies could be problematic to remove this residual EMF signal from the sensor signal. Therefore we explored, how important is the choice of the cut-off frequency of the digital high-pass filter separating the BN from the sensor signal.

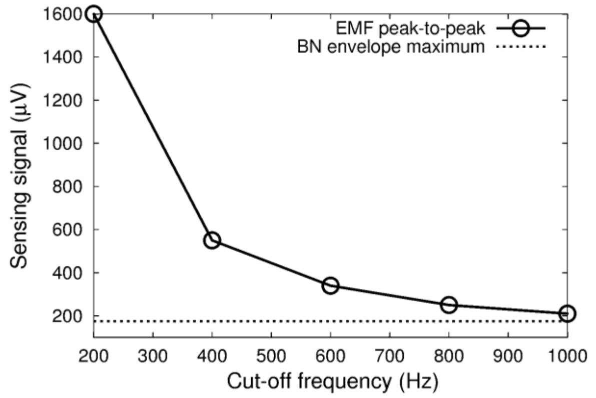

Fig. 8. The peak-to-peak value of the residual EMF signal as function of the cut-off frequency of the digital high-pass filter for the sample with the grain size of 28 μm and the magnetizing frequency of 10 Hz, dotted line shows the amplitude of the BN envelope obtained by the high-pass filter with the cut-off frequency of 1 kHz

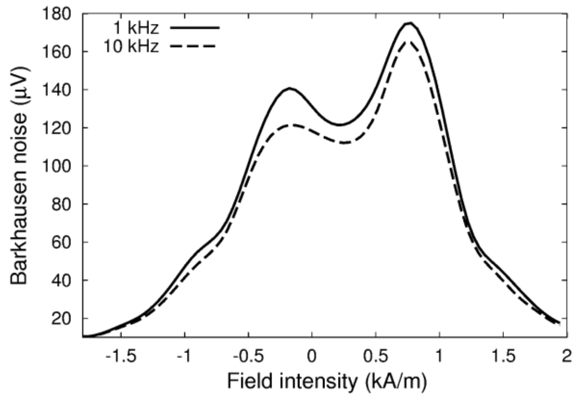

Fig. 9. The BN envelopes for the sample with the grain size of 28 μm and cut-off frequencies of the digital high-pass filter 1 kHz and 10 kHz, measured at the magnetizing frequency of 10 Hz

In Fig. 8, the influence of the cut-off frequency of the digital fifth-order Butterworth high-pass filter on the residual EMF signal (obtained by this filter) is depicted for the magnetizing frequency of 10 Hz. We can see that the residual EMF signal is suppressed on the level of the BN envelope amplitude at the highest cut-off frequency of 1 kHz. Below this cut-off frequency the peak-to-peak value of the residual EMF signal is higher or similar to the level of the BN envelope. To more reliable suppress the residual EMF signal, the cut-off frequency should be increased but this will also cause considerable reduction of the BN. This is demonstrated in Fig. 9, which shows that after increasing the cut-off frequency from previously used 1 kHz to 10 kHz the envelope of the BN significantly declined.

In contrast, when we increase the cut-off frequency 10 times for the signal measured at the magnetizing frequency of 1 Hz (see Fig. 10), the envelope of the BN is almost the same, since the BN in the frequency range from

100 Hz to 1 kHz is not as high as in the range from 1 kHz to 10 kHz. So measurements at magnetizing frequencies of 10 Hz and higher bring more complications with the filtering the measured signal than at smaller frequencies, especially in cases, when the residual EMF signal is relatively high.

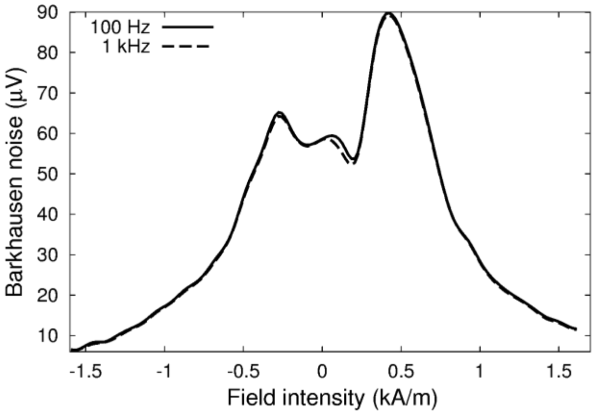

Fig. 10. The BN envelopes for the sample with the grain size of 28 μm and cut-off frequencies of the digital filter 100 Hz and 1 kHz, measured at the magnetizing frequency of 1 Hz

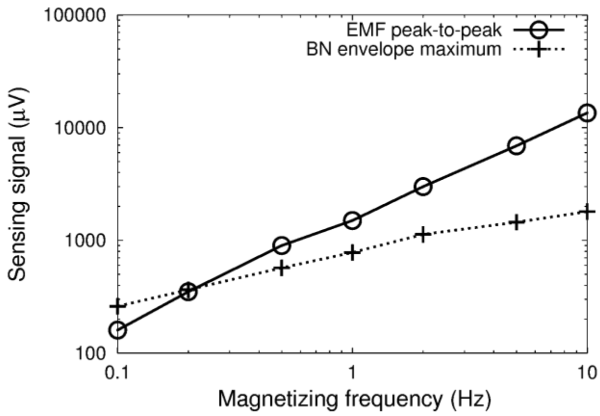

Fig. 11. The peak-to-peak value of the EMF signal and the amplitude of the BN envelope as functions of the magnetizing frequency for the sample with the grain size of 28 μm and the perpendicular sensing coil

Finally, we studied how large is the low frequency EMF signal, when the sensor is made as a perpendicular coil. In this case the sensor picks up the perpendicular component of the flux density change. The dependence of the peak-to-peak value of the EMF signal on the magnetizing frequency for the sample with the grain size of 28 μm is shown in Fig. 11. As we can see, the ratio of the peak-to-peak value of this signal to the amplitude of the BN envelope is only slightly smaller than in the case of two sensing coils connected in series opposition, so using the perpendicular sensing coil does not bring significant improvement in suppressing the low frequency EMF signal in our case.

4 CONCLUSIONS

Influence of the magnetizing frequency on the BN was investigated with emphasis on the correlation between the BN and the grain size of non-oriented FeSi steel. As one of the most pronounced problems in measuring the BN was assessed the low frequency EMF signal which interferences with the BN and it influences the accuracy of measurement, when it is not fully destroyed. Measurements prove that at magnetizing frequencies of about 10 Hz and higher there is problematic to filter the EMF signal without affecting the BN. Using the perpendicular sensing coil did not bring significant improvement in suppressing the EMF signal.

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REFERENCES

[1] SAKAMOTO, H. — OKADA, M. — HOMMA, M.: Theoretical analysis of Barkhausen noise in carbon steels, IEEE Trans. Magn. 23 (1987), 2236-2238.

[2] TIITTO, S.I.: On the mechanism of magnetization transitions in steel, IEEE Trans. Magn. 14 (1978), 527-529.

[3] RANJAN, R. — JILES, D.C. — RASTOGI, P.K.: Magnetic Properties of Decarburized Steels: An Investigation of the Effects of Grain Size and Carbon Content, IEEE Trans. Magn. 32 (1987), 1869-1876.

[4] BIRSAN, M. — SZPUNAR, J.A. — KRAUSE, T.W. — ATHERTON, D.L.: Magnetic Barkhausen noise study of domain wall dynamics in grain oriented 3% Si-Fe, IEEE Trans. Magn. 32 (1996), 527-534.

[5] PAĽA, J. — BYDŽOVSKÝ, J. — STOYKA, V. — KOVÁČ, F.: Barkhausen noise study of microstructure in grain oriented FeSi steel, Journal of Electrical Engineering 59 (2008), 58-61.

[6] BERTOTTI, G. — FIORILLO, F — SASSI, M.P.: Barkhausen noise and domain structure dynamics in Si-Fe at different points of the magnetization curve, J. Magn. Magn. Mater. 23 (1981), 136-148.

[7] HWANG, D.G. — KIM, C.G. — LEE, K.H. — KIM, H.C.: The retarding field model of Barkhausen noise and permeability in conventional and highly grain-oriented 3% Si-Fe polycrystals, Journal of Magn. and Magn. Mater. 125 (1993), 129-137.

[8] GATELIER-ROTHEA, C. — CHICOIS, J. — FOUGERES, R. — FLEISCHMANN, P.: Characterization of pure iron and (130 p.p.m.) carbon–iron binary alloy by Barkhausen noise measurements: study of the influence of stress and microstructure, Acta Mater. 46 (1998), 4873-4882.

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