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IMPACT OF FREQUENCY AND SAMPLE GEOMETRY ON MAGNETACOUSTIC EMISSION VOLTAGE PROPERTIES FOR TWO STEEL GRADES

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The paper presents the results of the analysis of the influence of magnetizing frequency and sample thickness on the magnetoacoustic emission signal properties. Various parameters such as the rms signal envelope, pulse distribution, and Fourier spectra (FFT) have been taken into account. In order to compare the influence of abovementioned factors with the effect of microstructure similar analysis has been performed for the sample made of steel of different grade.

Keywords: magnetoacoustic emission, nondestructive testing, signal analysis

1 INTRODUCTION

Magnetoacoustic emission effect (MAE) is now introduced in Poland for nondestructive assessment of microstructure modification mainly of steel exploited at power plant industry [1,2]. The MAE, it is in fact an acoustic signal generated during the movement of 90˚ domain walls, as a result of local volume changes in the material having a non-zero magnetostriction [3]. There are however many factors that influence the MAE voltage from the transducer. Main factor seems to be non-uniform space and time distribution of magnetic flux intensity inside the sample due to eddy currents. This distribution is a function of sample geometry and frequency of magnetisation and sample geometry [4].

2 EXPERIMENTAL

The experimental set-up is presented in Fig. 1. The sample (1) is magnetized using the encircling coil (2), supplied with current using a voltage-to-current power converter. The current intensity is proportional to the voltage, triangular in form, provided by the signal generator. The soft magnetic yoke (4) is used to close the flux path; the sample is acoustically isolated from the yoke by means of the sound attenuating separators (5). The MEA signal is detected using the PZT transducer (3).

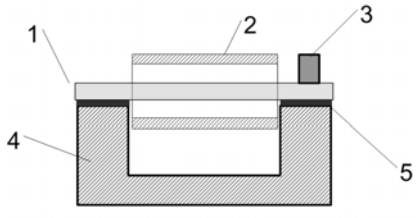

Fig. 1. The magnetizing set-up – descriptions in the text

The samples have been prepared in form of bars (130 mm in length, 20 mm wide and from 3 mm up to 10 mm thick). They are magnetised by solenoid using triangular like current with different frequencies (0.28 Hz to 13.1 Hz). The MAE detected by wide band transducer (100 kHz – 1 MHz) was recorded over one period of magnetisation with A/D 12 bit, 1 MHz PC card.

3 RESULTS

In order to analyse the influence of microstructure on the MAE signal two samples (of thickness 5.8 mm), made of (A) - 13HMF and (B) - St3 (polish steel grades) have been tested. The envelopes of the MAE signals for those samples are presented in Fig. 2. As can be seen the difference is very significant. Not only the intensity of signal for the (B) steel is much lower, but also the shape of envelopes is different – two separate maxima for the (A) steel and one broad peak for the other one.

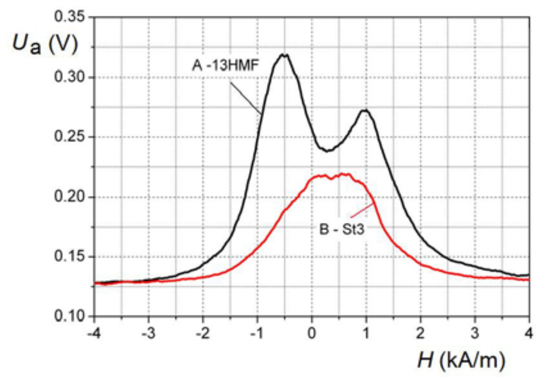

Fig. 2. MAE envelopes for different grades of steel

The next step was the analysis of the Fourier spectra (FFT) for the investigated samples. The results of such investigation are presented in Fig.3. As can be seen the difference is not so pronounced, the overall amplitude of the spectrum for the (B) steel is lower, but its shape is similar to the one observed for (A), the most pronounced difference observed for the lower frequencies (100-200 kHz). Such an analysis has a serious drawback, since it doesn’t give any information about the signal envelope giving the results for the whole period of magnetisation.

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In order to overcome such obstacle the time resolved Fourier analysis has been performed. It is in fact analogous to the standard FFT technique, yet the analysis is performed over small time intervals.

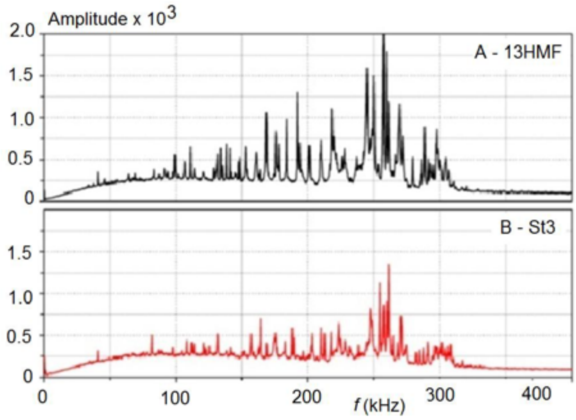

Fig. 3. FFT spectra for different grades of steel

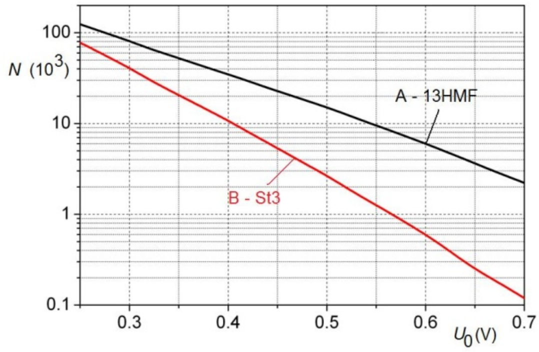

Fig. 4. Total number of counts as a function of the threshold voltage for different grades of steel

The results are presented in Fig. 5, as one can see the characteristic features of the signal envelope are reproduced; there are two maxima for the steel A (as a function of time) and one broad peak for the steel B. Over the frequency scale the dependence is similar to the one observed for the FFT spectrum, *ie* the biggest difference is observed for the frequency range close to 200 kHz.

Another characteristic feature of the Barkhausen noise signal is the number of pulses counted at various threshold levels. Fig. 4 presents the total number of count for both steels, as a function of the threshold voltage. As can be seen the number of pulses for the (B) steel is lower for all the threshold levels, yet the relative difference is biggest for the higher pulses. The only drawback of higher threshold levels is the fact that the number of pulses becomes low, decreasing the reliability of the results.

As can be seen it is quite easy to discern two different steel grades using the magnetoacoustic emission signal, provided that the measurement conditions remain exactly the same. In order to assess how crucial it is to perform measurements in strictly repeatable condition we have examined the influence of the sample thickness and magnetizing frequency on the MAE signal properties.

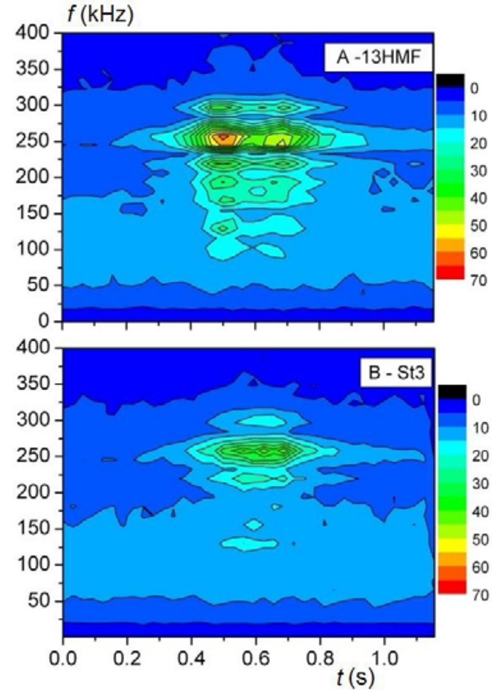

Fig. 5. The results of a time-resolved Fourier analysis for different grades of steel

The MAE signal envelopes obtained for samples with varying thickness, made of 13HMF steel are presented in Fig. 6. As can be seen the signal amplitude increases monotonically and the shape of the envelope doesn’t change much for the first three samples. As for the thickest sample the important broadening of the signal can be seen. Such effect is caused by eddy currents causing the phase shift of the magnetic flux density inside the material. As a result the MAE signals inside the material are generated somewhat later than in the regions close to the surface. Two examples of the results of the FFT analysis performed for the sample with smallest and biggest thickness are presented in Fig. 7. In contrast to the results obtained for different steel grade the shape of spectra differs significantly.

After analysing the entire spectra one can say that the thicker the sample, the bigger the content of lower frequencies in measured signal. Thus the FFT spectra are

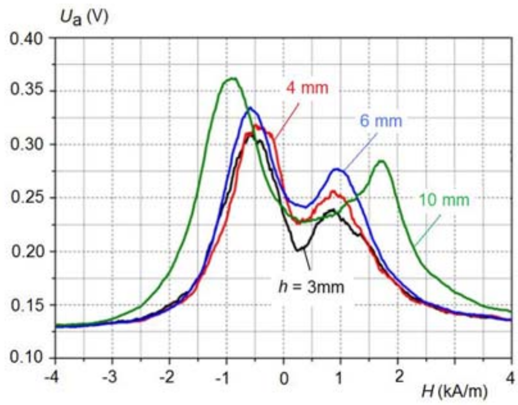

Fig. 6. MAE envelopes for samples of different thickness

much more strongly affected by the thickness of the sample than by the material properties.

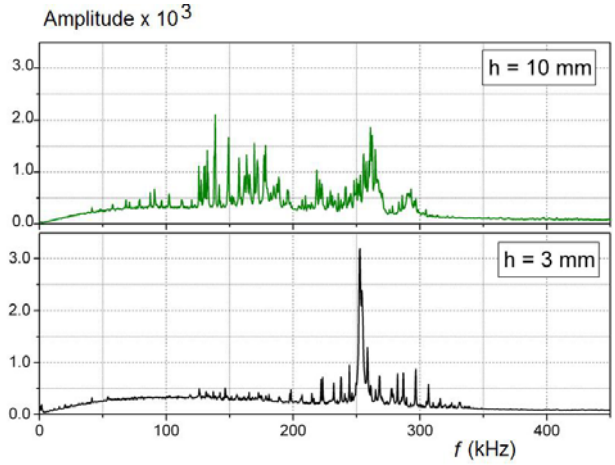

Fig. 7. FFT spectra for samples of different thickness

Another issue concerning the measurement conditions is the magnetizing frequency. In order to investigate that matter the thickest sample has been chosen, since in such a thick sample the influence of the eddy currents is expected to be the strongest. The envelopes of the MAE signals obtained for different (h = 10 mm) frequencies are resented in Fig. 8. As can be seen with increasing frequency the intensity of the MAE signal also increases, and the increase is quite strong.

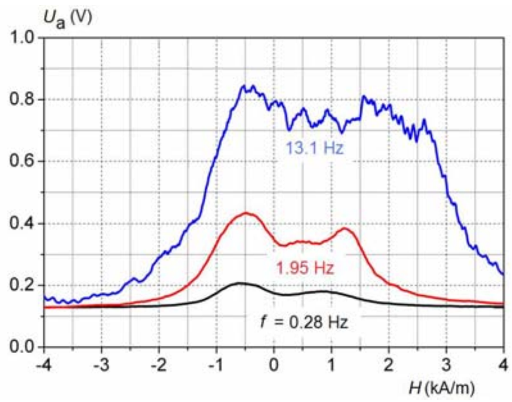

Fig. 8. MAE envelopes for different magnetizing frequencies

The shape of the envelope changes initially only slightly, yet for the higher frequencies the two separate maxima start to disappear and a broad plateau is observed. Such a broad maximum is a characteristic feature of samples magnetised with relatively high frequencies. In such a case the phase shift between the "layers" of the material is so big that the maxima of the signal generated inside the material overlap with the minima from the close to surface "layers". To quantify the observed increase the integrals of the MAE voltage (Ua) over half-period of magnetization have been calculated, such quantity is often used as measure of the MAE signal intensity. The dependence of such intensity on the magnetizing frequency is presented in Fig. 9. The

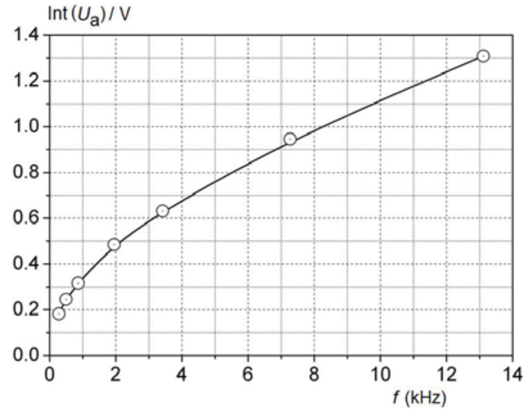

Fig. 9. MAE signal intensity as a function of magnetizing frequency

character of the dependence is similar to the square-root dependency. It may be expected that the increase should be linear, yet due to the detrimental effect of eddy currents, lowering the magnetisation level inside the material, the observed dependency can be understood. The results of the FFT analysis for different magnetizing frequencies (see Fig. 10) are somewhat surprising, as there is almost no change in the shape of the spectra, while the amplitude of the signal increases several times for various frequencies.

The MAE signals obtained for various magnetising frequencies have been also subjected to the pulse analysis. The total number of pulses as a function of the threshold voltage level is presented in Fig. 12. One can observe that the higher the magnetizing frequency the higher the content of pulses of relatively high amplitude. Such behaviour doesn't necessarily mean that the MAE pulses generated during a single domain wall movement become bigger. It may well be due either due to the collective motion of many domain walls at such high magnetization rates or to the clustering of pulses generated by various, independent sources.

4 DISCUSSION

As can be seen the difference in the MAE signal parameters for different kind of steels may be quite high, thus allowing to hope that a technique based on the MAE measurements may become a valuable tool for the structure characterization. The problem arises when one has to examine sample of different geometry in the industrial environment. The thickness of the material can influence the signal intensity; it is not a problem if one knows exactly the thickness of the tested material. In such a case a correction coefficient can be applied, yet the issue is complicated while examining closed elements from the outside e.g. pipelines. In such a case a more advanced signal analysis is necessary. Fortunately, as it turns out, the FFT spectrum is very sensitive to the thickness of the investigated sample, far more than to the microstructural features. It may seem strange as the MAE signal is generated during abrupt jumps of 90 deg magnetic domain walls, and such jumps should be correlated with microstructural features. The pinning strength of precipitates, dislocation tangles, etc. should affect the magnetization level at which jump occurs as well as the size of a single jump. The reason of such behaviour of the signal arises from the fact that one cannot in reality detect the single jump events but a result of the interaction of generated acoustic wave with the sample geometry. The acoustic wave generated during a single event is not strongly attenuated in the steel sample and hits the transducer several times before it fades out completely. The strongest signal is obtained for the acoustic waves close to resonant frequencies of the investigated samples.

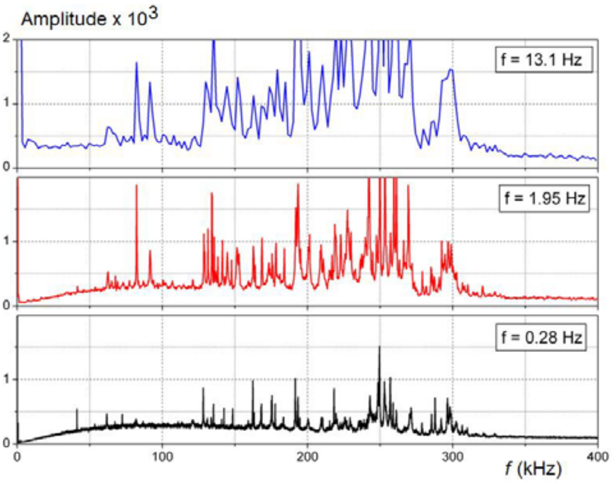

Fig. 10. FFT spectra for various magnetizing frequencies

As can be easily understood the bigger the thickness of the sample the lower the resonant frequencies. Analogous dependence is easily found on the MAE Fourier spectra (see Fig. 7), for the thin sample (h = 3 mm) the low frequency component are practically absent, while for the thickest one the content of the components from the frequency range 100-200 kHz is similar to that of the 200-300 KHz. Such interaction between acoustic signal and sample geometry is confirmed by the test performed for different magnetizing frequencies. For higher frequencies one might expect strong clustering of the generated pulses and strong changes in the spectra of the detected signal, yet such changes are not observed. The spectra obtained for the all the frequencies are qualitatively similar thus confirming the assumption of the dominant influence of the geometry.

A characteristic feature of the signals obtained for higher magnetizing frequencies is the bigger content of the higher pulses. Such behaviour may be explained by the overlapping of the pulses generated at near enough locations. The higher the frequency, the higher the magnetization change rate and hence the smaller time between the single jumps. It is also possible that the higher rate of magnetization change affects the interaction between domain walls leading to their collective motion. There should be also addressed an effect of time-space modification of magnetic flux inside the 'thick' sample due to eddy current effect. This complex behaviour is now also under consideration [4]. All these effects should be thus taken into account when industrial objects are tested by means of magnetoacoustic emission phenomenon.

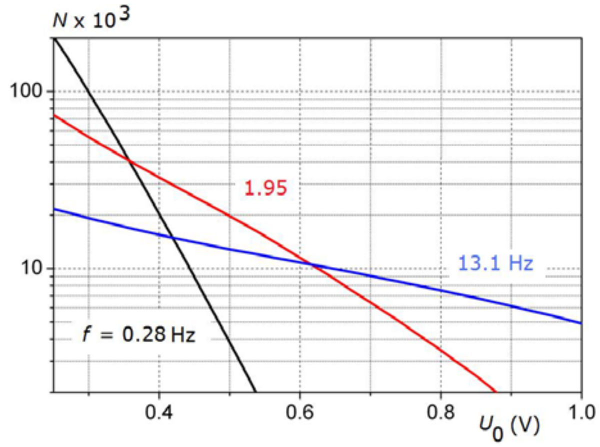

Fig. 11. Total number of counts as a function of the threshold voltage for various magnetizing frequencies

5 CONCLUSIONS

The MAE is correlated with the microstructural futures of the tested steels and allows for the detection of the signals from the whole magnetized volume thus giving the opportunity to investigate the bulk properties, unlike for instance the Barkhausen effect. Being so, the MAE should be a very effective non-destructive technique of the material assessment. The as shown important impact of sample geometry or magnetization frequency on MAE properties should be quantitatively evaluated by means of impact of eddy current on space and time distribution of flux density inside the body.

REFERENCES

[1] AUGUSTYNIAK, B. – CHMIELEWSKI, M.- PIOTROWSKI, L.- SABLIK, M. J.: "Designing a Magnetoacoustic Emission Measurement Configuration for Measurement of Creep Damage in Power Plant Boiler Tubes"; J. Appl. Phys. **91** (2002), 8897-8899;

[2] AUGUSTYNIAK, B. - PIOTROWSKI, L. - CHMIELEWSKI, M. - SABLIK, M. J.: Nondestructive Characterization of 2Cr-1Mo Steel Quality using Magnetoacoustic Emission, IEEE Trans. Magn. **38**, No. 5 (2002), 3207-3209,

[3] B. AUGUSTYNIAK, B. - SABLIK, M. J. - LANDGRAF, F. J. G. - JILES, D. C. - CHMIELEWSKI, M. - L. PIOTROWSKI, L. – MOSES, A. J.: Lack of magnetoacoustic emission in iron with 6.5% silicon; J. Magn. Magn. Mater. **320** (2008), 2530–2533

[4] AUGUSTYNIAK M. - AUGUSTYNIAK B. - PIOTROWSKI L. - CHMIELEWSKI M. - SADOWSKI W.: Evaluation by means of magneto-acoustic emission and Barkhausen effect of time and space distribution of magnetic flux density in ferromagnetic plate magnetized by a C-core; J. of Magn. Magn. Mater. **304** (2006), e552-e554

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