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INVESTIGATION OF CORRELATION BETWEEN HYSTERESIS AND BARKHAUSEN NOISE MEASUREMENTS

Oleksandr Stupakov* — Jozef Paľa — Jan Bydžovský** — Ivan Tomáš* — Peter Švec*****

The main aim of this paper is to discuss the applicability of hysteresis and Barkhausen noise measurement methods to industrial tasks and to investigate the correlation of the results, obtained by these two magnetic techniques. The magnetic inductive and the Barkhausen noise measurements at different experimental configurations were done on a model series of open flat samples. The results proved the correlation between magnetic differential permeability and Barkhausen noise envelope. However, significant quantitative discrepancies between them have been also obtained. The reasons of these deviations are discussed in order to unify and standardize the magnetic hysteresis and the Barkhausen noise techniques.

Keywords: magnetic hysteresis measurements, Barkhausen noise measurements, magnetic non-destructive testing

1 INTRODUCTION

Despite of long history of magnetic measurements, at the moment there is no widely accepted, easy-to-use and stable technique for evaluation of magnetically *open* samples, i.e. flat sheets/strips [1]. The standard techniques, *eg* Epstein or single sheet tester, are either too robust for modern industrial tasks or unstable to small deviations of the measurement conditions. In laboratories the open samples are usually tested by a single-yoke setup carrying a magnetizing coil. In case of the hysteresis measurements, the induction signal is measured by a sensing coil, wound either on the sample or on the yoke. This induction signal is referred to the magnetizing current or to the magnetic field, measured by a Hall sensor above the sample surface [2]. In case of the Barkhausen noise (BN) measurement, quite different approaches are used. The BN signal can be measured either by a sensing coil, wound directly around the sample body, or by differently constructed read-heads, attached to the sample surface to pick up the normal component of the BN jumps. The BN signal, obtained in such ways, is usually referred simply to the magnetizing current [3].

This work is devoted to investigation of correlations between the inductive hysteresis and the BN techniques in order to propose the best solution for magnetic non-destructive testing (NDT) of open industrially shaped constructions. For this purpose the above-mentioned experiments were performed in different practically used configurations with the aims to analyse similarities and distinctions between the different measurement methods.

2 EXPERIMENT

The measurements were done on a model series of flat samples of low-carbon steel CSN (0.07-0.15%C, 0.3-0.5%Mn, 0.17-0.37%Si, max.0.15%Cr, max.0.25%Cu, max.0.04%P, max0.04%S), used for large diameter pipelines at power plants. The tested samples with dimensions 90x50x6 mm^3 underwent uniaxial plastic tension to 0, 8, 10, 13 and 15 % of strain along the longer side of the samples. The measurements were done after unloading along the stress direction. The residual plastic deformation leads to an interesting magnetic behaviour with two-peak profiles of the differential magnetic permeability and of the BN envelope [4]. This was the main reason of choice of this sample series for the proposed measurements in order to compare these unusual shapes of the permeability and of the BN envelope.

The samples were measured by a magnetizing single-yoke (transformer C-core) of the same width as the samples (see Fig. 1). Triangular waveform of the magnetizing current was used. The inside-sample field H_i was evaluated to be proportional to the magnetizing current I: $H_i=NI/l$, where N=320 is a number of magnetization windings, and magnetic path l was defined as equal to 58 mm. The used field rate was dH_i/dt=2.2 kA/m/s. The induced voltage is pick-up by the sensing coils, wound around the samples and around the yoke legs.

The BN signal was also measured by two methods: by the same sensing coil, positioned around the samples, and by a read-head of 2000 wire turns with the core of stacked soft amorphous ribbons, positioned at the sample surfaces between the yoke legs (see Fig. 1). The BN signals were sampled with 25 kHz rate and then digitally filtered cutting the low-frequency components up to 1 kHz for the sample induction coil and 0.3 kHz for the read-head. The BN envelopes were obtained by 500 point RMS averaging and by a consequent gentle smoothing.

Additional measurements of angular dependence of the BN response with respect to the stress axis were done with the help of a specially designed miniature BN sensor. It is of similar single-yoke construction with a ferrite read-head between the yoke legs and a built-in amplifier for increasing signal/noise ratio. The yoke width is 7 mm with the 2x3 mm^2 legs. The results were compared with “the large-yoke” configuration with the same aim of seeking the most suitable way for magnetic NDT.

*Institute of Physics, ASCR, Na Slovance 2, 18221 Praha 8, Czech Republic, E-mail: stupak@fzu.cz
**Slovak University of Technology, Department of Electromagnetic Theory, Ilkovičova 3, 81219 Bratislava, Slovakia, E-mail: pala@iris.elf.stuba.sk
*** Institute of Physics, SAS, Dúbravská cesta 9, 84511 Bratislava, Slovak Republic.

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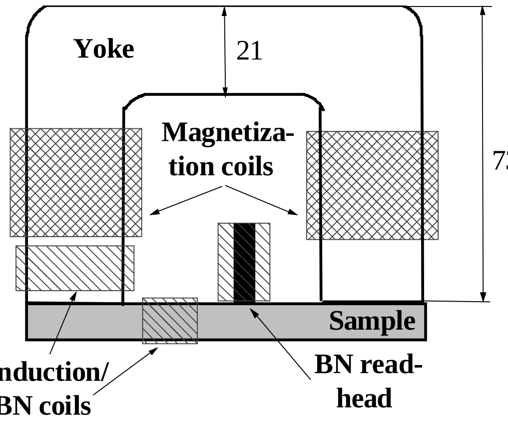

Fig. 1. Principal scheme of the measuring setup.

3 EXPERIMENTAL RESULTS

Results of the measurements with the setup, shown in Fig. 1, are presented in Figs. 2-4 by the example of the non-deformed and the 8 % strained samples. The deformed samples showed results very close to each other. Fig. 2 presents the differential permeability curves, measured by the induction coils on the sample and on the yoke. It can be seen that the permeability, measured by the yoke coil, is always a little higher than that, measured by the sample coil. The real permeability curve with μ_{max}≈4x10^3 of the non-deformed material, measured classically on a closed ring-shaped sample carrying the magnetizing and induction windings, is shown for comparison. Figs. 3-4 show comparison of the differential permeability curves and the BN envelopes, measured by the sample induction coil and by the read-head. It can be seen that the curve profiles do qualitatively correspond to each other: the signal values are gradually decreased with the deformation showing the two-peak profiles. However, there are significant quantitative distinctions between these signals.

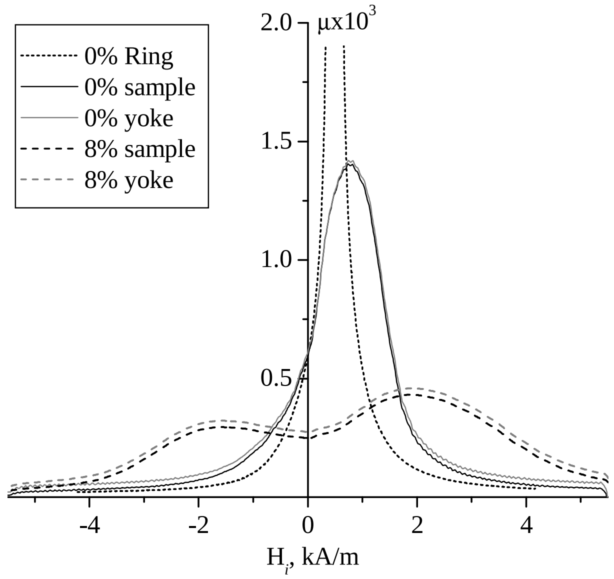

Fig. 2. Differential magnetic permeability for the non-deformed and the 8% strained samples, measured by the induction coils on the samples and on the yoke. Real permeability curve of the non-deformed material, measured classically on a closed ring, is shown for comparison.

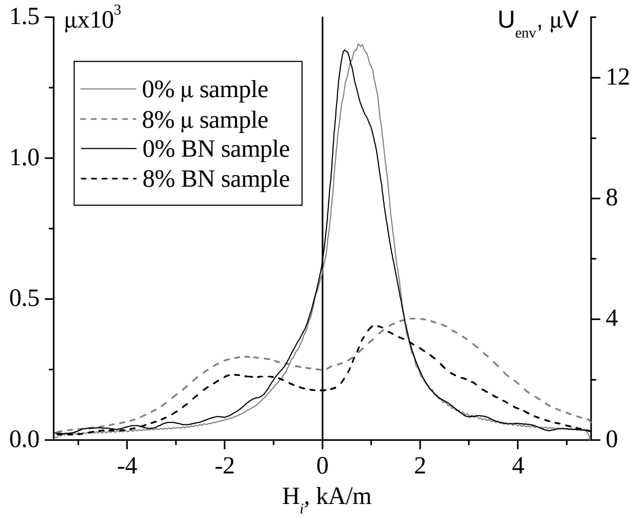

Fig. 3. Comparison of the differential permeability μ (left scale) and the BN envelope U_{env} (right scale), measured by the sample induction coil, for the non-deformed and the 8% strained samples.

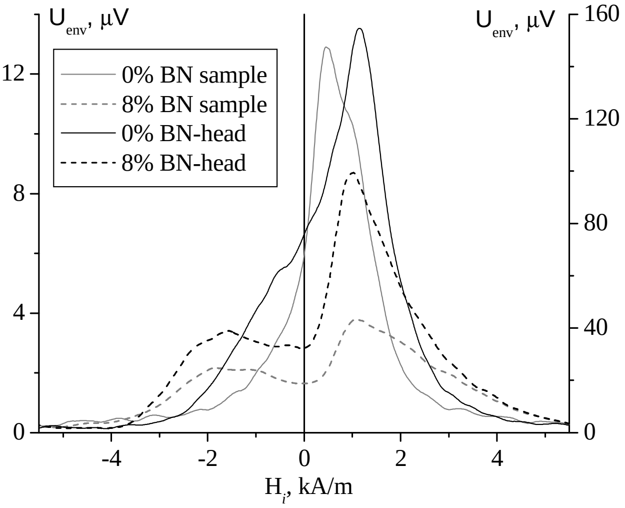

Fig. 4. Comparison of the BN envelopes U_{env}, measured by the sample induction coil (left scale) and by the read-head (right scale), for the non-deformed and the 8% strained samples.

Figs. 5-7 present the BN envelopes, obtained with the miniature read-head at different magnetization directions with respect to the stress axis. According to our knowledge such results have not been published before. Due to impossibility of evaluation of the inside-sample field with such a setup configuration, the envelopes were shown with reference to the magnetizing current *I*. Figs. 5 and 6 show that the BN level is decreased with the deformation in the investigated strain range. The direction perpendicular to the stress is magnetically softer than that along the previous deformation. It can be also seen from Fig. 7, which shows an increase of the BN level and a shift of the envelope maximum to lower magnetizing currents with the read-head rotation away from the stress direction. However, the used miniature read-head was not able to distinguish the two-peak shape of the envelopes for the deformed samples. Moreover, it demonstrated lower sensitivity to the deformation compared to the “large-yoke” configuration.

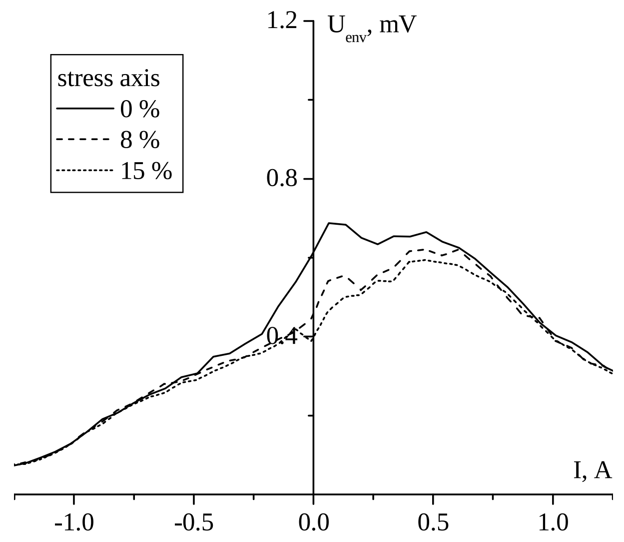

Fig. 5. BN envelops, measured by the miniature read-head, for differently strained samples along the stress direction.

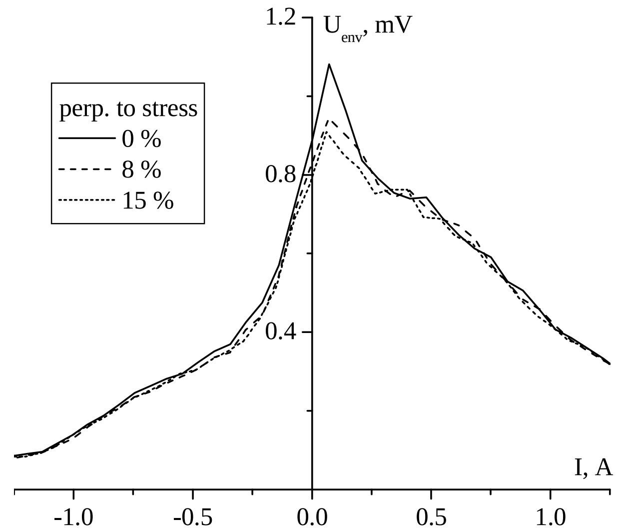

Fig. 6. BN envelops, measured by the miniature read-head, for differently strained samples perpendicularly to the stress direction.

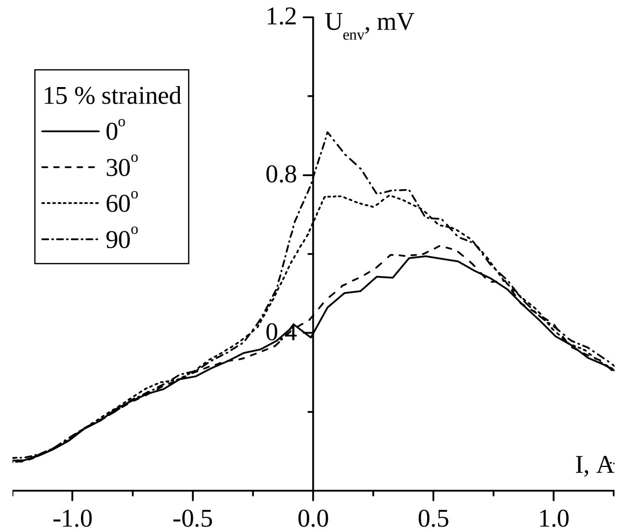

Fig. 7. BN envelopes, measured by the miniature read-head, at different angular positions between the magnetizing and the stress directions for the 15 % strained sample.

4 DISCUSSION

The obtained results follow the expected trends. The hysteresis/permeability measurement is a more standard method leading to determination of the sample magnetic response (magnetic induction/flux) to the sample magnetization (magnetizing current/sample field). The magnetic induction signal is much higher, less noisy, and easier for further interpretation than the BN. The measurements can be always verified on the requirement of the hysteresis symmetry or by the maximum induction value. However, mobility demands ask for position of the induction coil on the yoke body rather than on the sample. This leads to overestimation of the sample flux due to additional measurement of the leakage flux between the yoke legs together with the useful signal from the tested sample. Moreover, the yoke induction coil evaluates the magnetic flux, which generally penetrates into the sample volume in a non-homogenous way [5]. However, the main disadvantage of this method still remains the so-called “contact problem”: the considerable dependence of the measurement results on the contact quality between the yoke and the sample. To say it in another way, the frequently-occurred and poorly-defined small air-gaps between the attached yoke and the tested industrially-shaped samples lead to fluctuations of the magnetization conditions, i*e* the field rate, and correspondingly lead to changes of the induction signal. In order to reduce this problem, the hysteresis single-yoke measurements are often performed with the parallel determination of sample surface fields [2,5], but even this method does not solve the trouble completely.

Therefore, the BN testing with the help of the surface-attached read-head seems to be attractive for practical use in the NDT field. The BN heads are of small size making them suitable for *local* material evaluation between the yoke legs. However, there is still no clear understanding of correlations between the hysteresis and BN characteristics and there is still no standard widely accepted scheme of the BN measurements. There are very different constructions of laboratory-used BN sensors, as well as there is a lack of information about stability of the method with respect to deviations of the measurement conditions, *eg* to introduced air-gap between the BN sensor and the sample surface [3,6,7]. Therefore, the main aims of this work were to investigate some of these open problems and to discuss applicability and limitations of the BN technique.

For this purpose, the good laboratory setup with big magnetizing yoke and without sample overhang was utilized first. This setup configuration provides near-homogenous magnetization of the tested samples [5,8]. The presented results (see Figs. 2-4) proved the theoretical expectations about physical correlation between the hysteresis and the BN processes [9]. The BN envelopes showed similar two-peak behaviour as the differential permeability for the uniaxially deformed samples. However, at such ideal measurement conditions, quantitative deviations between the different types of the measurements are evident. Moreover, even the BN envelopes, measured by the induction coil and by the read-head, are quite different (see Fig. 4).

An opposite experimental configuration with a small magnetizing yoke was tested by the example of the miniature BN read-head. This sensor attracts attention due to its mobility and small dimensions. Results of its measurement are also independent on the sample shapes and sizes [8]. However, another negative side of the coin is that the tested sample is magnetized only inside the small volume under the yoke legs. The sample magnetization is far from saturation and strongly inhomogeneous through the tested volume. This could lead to additional instability of the measurement results with respect to the yoke-sample contact [2,5].

The results, shown in Figs. 5-7, proved these statements. In-situ minor loop measurements cannot distinguish the two-peak profiles of the deformed samples [7]. However, this is the single possible way of measurement of angular dependences of the magnetic characteristics for the samples of an arbitrary shape, and it did give the results. The measurements demonstrated that the deformed samples are magnetically softer in the perpendicular direction to the previous elongation with lower sensitivity to strain, which was predicted in our preceding works for differential permeability [7,8].

Despite of the long history of BN measurements, evaluation of the BN envelope is a quite new topic. In contrast to its main predecessor, classical total RMS value of BN, processing of local RMS profile of BN is more complicated and less stable. However, it can give deeper understanding of the underlying physical processes. Nowadays the BN envelopes are mostly presented with reference to the magnetizing current as it was also done in this work [7]. Lively discussions are devoted to explanation of obtained BN profiles due to different sensitivity of the used measurement methods to the various stages of magnetization process: nucleation/annihilation/movement of the $90^o/180^o$ domain walls [10]. This should be really one of the principal reasons of quantitative disagreements between different methods of the BN measurement, in particularly between the methods of the sample induction coil and the BN read-heads. The heads record the BN jumps in the perpendicular direction to magnetization, whereas the coil picks up the noises from the sample surface along the magnetization line. However, another reason of the considered deviations, especially between the differential permeability and the BN envelopes, can be due to the use of the magnetizing current as a reference value. It was shown in our recent works [2,5,7] that evaluation of the sample field by direct surface field measurements stabilizes the contact problem and gives more reasonable values of magnetic parameters. Therefore, additional investigation of the considered problems with real sample field determination is needed for clarifying the topic in details.

5 CONCLUSIONS

The investigation of the hysteresis and the BN techniques based on the single-yoke magnetization was performed with the aim to find correlations between these conjugate measurement methods and to discuss the optimum design of a magnetic NDT device. The experimental results proved that despite of the close relationship between the hysteresis and the BN signals there are substantial quantitative deviations between them, which are additionally dependent on the setup configurations. This makes a barrier on the way towards the measurement unification and towards development of the magnetic inductive method to a standardized NDT procedure. To clarify the main reasons of these discrepancies it was proposed to refer the BN envelopes to the measured surface sample field.

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