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doi:10.15199/48.2017.07.07

# Comparison of the results of the Barkhausen noise investigations conducted with using various designs of sensor

***Abstract**. The paper present results of the Barkhausen noise investigations of the steel samples, conducted with using three different design of the measurement sensors. The study were performed at the same reference conditions for each sensors. The character and scale of the obtained differences were analysed and discussed.*

***Streszczenie.** W artykule przedstawiono rezultaty badań szumu Barkhausena w stalowych próbkach, prowadzonych z użyciem trzech różnych konstrukcji czujników pomiarowych. Pomiary dokonano w tych samych warunkach odniesienia. Charakter i wielkość występujących różnic zostały poddane analizie i dyskusji. (**Porównanie wyników badań szumu Barkhausena prowadzonych z użyciem różnych konstrukcji sensorów).***

**Keywords:** Barkhausen noise, design of sensor, air coil, core coil
**Słowa kluczowe:** szum Barkhausena, konstrukcja czujnika, cewka powietrzna, cewka z rdzeniem

## Introduction

Nondestructive methods based on the Barkhausen noise measurement are widely used for ferromagnetic materials testing. It allows to rapid control of properties of manufactured products in process of metal forming, rolling, welding or heat treatment. Also the automation of control procedures is easy and measuring equipment is relatively cheap and safely to the staff. The physical principle of these testing methods relies on well-known effect (discovered by H. Barkhausen in 1919) of jerky motion of the magnetic domains' walls between pinning sites during magnetization process. It result in discontinuous magnetic flux density changes inside the material, inducing in a pick-up coil series of electrical pulses, which after conditioning take characteristic form called magnetic Barkhausen Noise (BN). Course of this phenomenon is determined by a lot of materials properties as microstructure type, grain size, texture and mechanical stress level [1]. Also the magnetization conditions as well as measuring set-up parameters have considerable impact on the results of its measurements. Individual research teams use own measuring set-up and commercial solutions are cryptic. Especially, due to lack of detailed standards of Barkhausen noise sensors construction, results received in laboratory investigations as well as industrial applications [2] with different measuring head may be various. For this reasons, to conduct research on construction of detection sensor seems to be right to check and recognize exemplary differences caused by its sensitivity and measurement resolutions. This issue was analyzed in [3, 4], but due to various magnetization conditions, the results cannot be fully compared and clear.

## Experiment and material

The magnetic Barkhausen noise measurements were carried out using the stand-alone measurement equipment for excitation, detection and processing of BN developed at Technical University of Częstochowa by author [5]. During the investigations, the raw Barkhausen noise signal and its root mean square value $BN_{RMS}$, envelope $BN_{EN}$ as well as the magnetization conditions current $I_m$ and frequency $f_m$ were recorded. In Figure 1, schematic block diagram of measuring set-up was presented.

To maintain stable and repeatable magnetizations conditions, during examination of each detection sensor, the same detached magnetization yoke with 400 turn of windings was used (Fig. 2). Average magnetic flux path length $l_{av}$ yoke – material was about 120 mm.

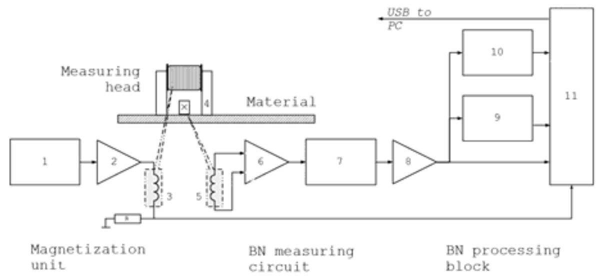


Fig.1 Block diagram of measurement set-up: 1 – saw-tooth generator, 2 – current power amplifier, 3 – magnetization coil, 4 – yoke, 5- detection coil, 6 – preamplifier, 7 – high pass filter, 8 – amplifier, 9 – RMS converter, 10 – envelope detector, 11 – DAQ unit, R – resistor (1Ω)

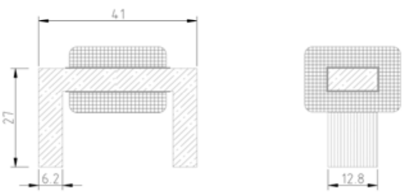


Fig.2 Schematic view of magnetization yoke used during study

During the tests, three different kind of surface detection sensors of BN (Figure 3) were examined, as:

1 - air coil with diameter 10mm, and 300 turn
2 - ferrite pot-core, with cross surface, ca 150 mm2 and 200 turns
3 - ferrite drum-core, with cross surface, ca 12 mm2 and 200 turns

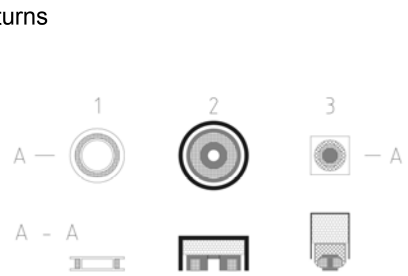


Fig.3 Schematic view of BN detection sensors used in experiments

The investigations were performed on the two samples (Figure 4). The first one was laboratory specimen used to tensile strength test, plasticity deformed. On the surface of the deformed section, 12 measurement points with distance 5 mm were indicated. The second specimen was a steel sheet, rolled with using semi-industrial two high rolling mills and freely cooled. It had initial dimensions: 200 mm × 350 mm × 5 mm. On the one side, lattice of the measurement points was marked. The distance between main, nine measurement points was 50 mm and 10 mm between local points, which were cross arranged.

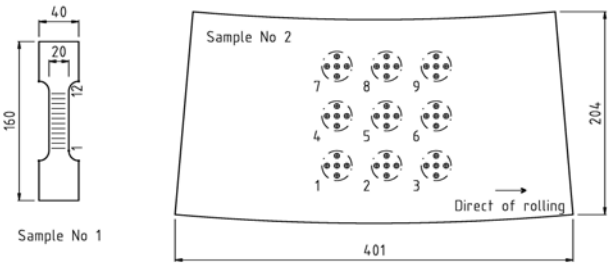


Fig.4 Dimension and measurement points localization of the investigated samples.

Both samples were made from the same S235JGR2 grade of pearlitic - ferrite steel, although obtained from different factory batches. In both case any, additional surface preparation or heat treatment were not applied to the samples, especially to the rolled sheet to keep as raw conditions as in real industrial process.

First stage of experiment covered determination of specific characteristics as $BN_{RMS} = f(I_m)$ in the first sample and $BN_{RMS} = f(f_m)$ in second sample, with using each of the tested sensors. These measurements were performed as a 1 second length one shoot.

In the second stage of the study, the measurement of the root mean square value of BN in neighbouring points in the samples were performed, in purpose to recognize and compare resolution properties of investigated sensors.

**Results and discussion**

In Figure 5 example of the Barkhausen noise waveform was presented. It has been acquired by the air coil in central, measurement point on the investigated steel sheet. It has typical shape for the low-mild steel. Extracted from the raw BN envelopes plots, recorded by each tested sensors, were presented in Figure 6. Quantitative disproportions between ferrite pot core and others resulted from its considerable higher sensitivity. And although at first glance noticeable qualitative differences has not been occurred, in fact, comparison of the normalized envelopes let to conclude that peaks for air and drum core coils were more narrowed.

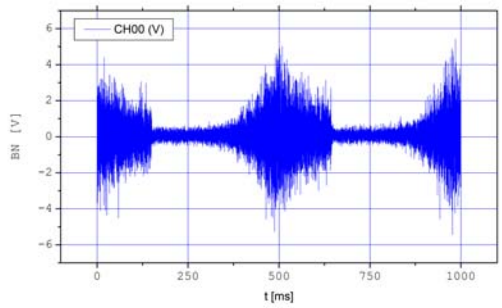


Fig.5 Example of acquired Barkhausen noise

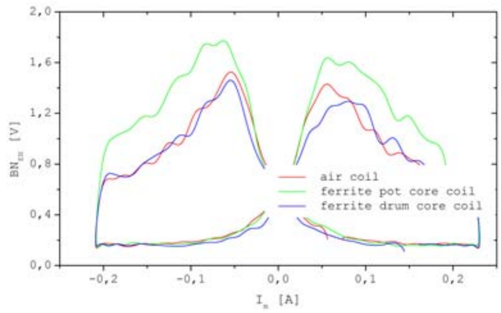


Fig.6 Barkhausen noise envelopes

In Figure 7, variation of the $BN_{RMS}$ with magnetization current $I_m$ was shown. For each design of detection coil, these curves had the same sigmoid shape. As expected, a characteristic for ferrite pot core coil was above others. Moreover, on the basis of the mutual vertical position of the other two characteristics in plateau, higher sensitivity of air detection coil than drum core coil has been found. Analogical relationships were revealed for characteristics of variation of the $BN_{RMS}$ with magnetization frequency $f_m$ (Fig. 8) which in the analyzed range of the frequencies (1 .. 38 Hz), these curves can be mathematically described with exponential decay function.

Observing normalized both types of characteristics (Fig 9 and 10), can be concluded, that for all kinds of tested sensors, their course has the same quality. Noticeable, small differences for $BN_{RMS} = f(I_m)$ characteristic resulted from *one shoot* methodology of doing the measurements in this case.

Next stage of the experiments covered investigations of linear measurement resolutions and uncertainty. The yoke with the selected pick-up coil were moved with 5 mm step along the centerline on the first sample (Fig. 11).

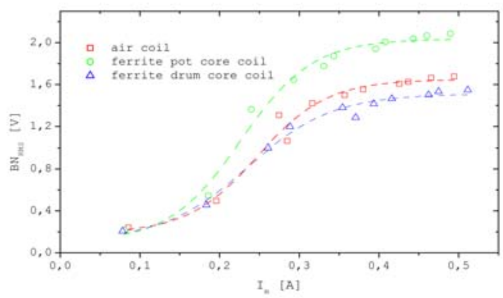


Fig.7 Variation of the $BN_{RMS}$ with magnetization current $I_m$

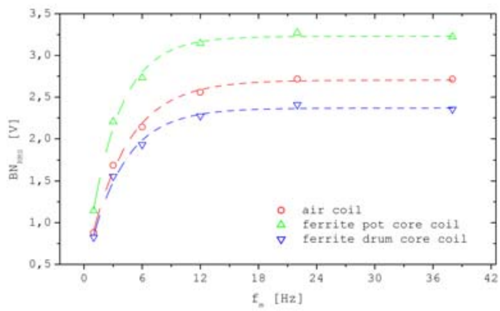


Fig.8 Variation of the $BN_{RMS}$ with magnetization frequency $f_m$

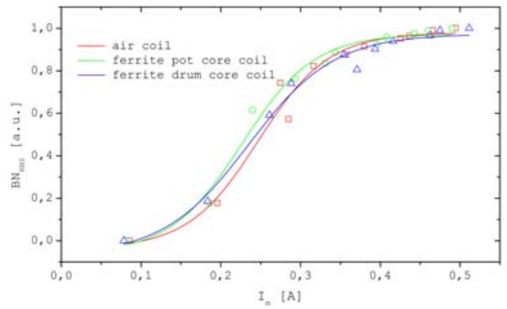


Fig.9 Variation of the normalized $BN_{RMS}$ with magnetization frequency $f_m$

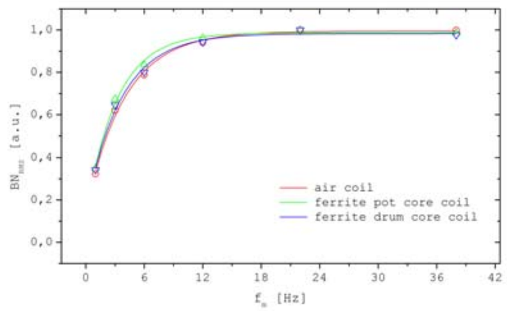


Fig.10 Variation of the normalized $BN_{RMS}$ with magnetization frequency $f_m$

Received profiles of $BN_{RMS}$ changes (averaged from three passes) in particularly points were shown in Figure 12. Although they have similar courses, the correlations between each pair of normalized characteristics were tested (Table 1). For each case, good linear correlation ($r$ > 0,8) with statistical significant level ($p$-value < 0,001) was found. Despite of it, analyze of the mean percentage of absolute differences between two neighboring points was 5,2% for air coil, 7,3% for pot core coil and 7,4% drum core coil. It pointed, that first sensor has the most "averaged" property.

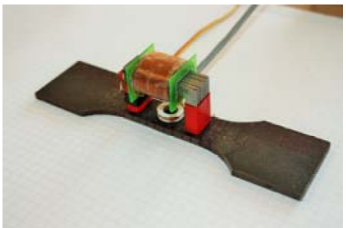

Fig.11 Details of experiment on the first sample - air coil sensor.

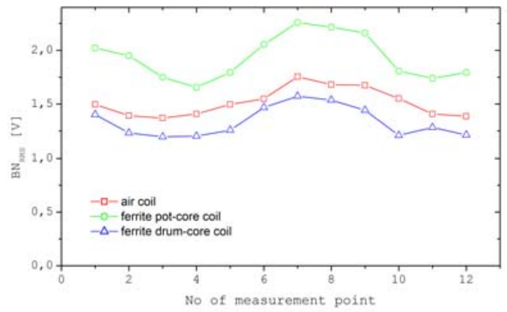


Fig.12 Profiles of $BN_{RMS}$ changes

Table 1. Correlation between pairs of measured BN profiles

| Pair of profiles | | $r$ | $p$ |
|---|---|---|---|
| Air coil - | Pot-core coil | 0,86 | 0,00033 |
| Pot-core coil - | Drum-core coil | 0,93 | <0,0001 |
| Drum-core coil - | Air coil | 0,87 | 0,00026 |

In Figure 15, results of the multipoint Barkhausen noise measurements by different sensors in the hot rolled steel sheet (Fig. 13) were shown. In order to compare them, measured values of $BN_{RMS}$ were normalized and presented as bars. For better visibility, in each main point, middle data were omitted. As can be observed, there were no special rules - in some points the results were consistent and in others are different. It depends on distribution of changes in material and mechanical properties of the investigated specimen, constituted by manufacturing process. To check if the measurements ($n$ = 45) were statistically different, the t-Student test was performed between results obtained for each combination of sensors' pair. In each case, these differences were statistically significant, for $p$-value = 0,01 (Table 2). Graphical results of the calculations (Figure 14) shown also that the smallest standard deviation of all measurements were for the air coil (sensor 1), and the biggest for the coil with drum core (sensor 2). This is consistent with previous findings, obtained for the tensile strength sample.

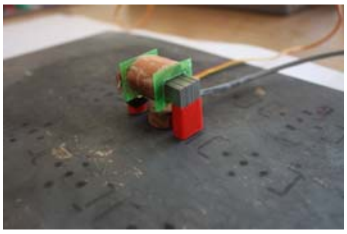

Fig.13 Details of experiment on the second sample - pot core sensor.

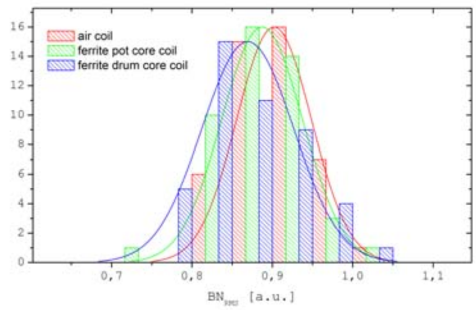


Fig.14 Categorized data of multipoint BN measurements in the steel sheet sample.

Table 2. Statistical calculations of multipoint BN measurements. Normalized data.

<table>
<tr><th colspan="2" rowspan="2">Coil</th><th colspan="2">BN<sub>RMS</sub></th><th rowspan="2">p</th></tr>
<tr><th>mean</th><th>st_dev</th></tr>
<tr><td rowspan="5">Pair</td><td>Air</td><td>0,90211</td><td>0,046</td><td rowspan="2">0,00779</td></tr>
<tr><td>Pot-core</td><td></td><td></td></tr>
<tr><td>Pot-core</td><td>0,88717</td><td>0,051</td><td rowspan="2">0,00265</td></tr>
<tr><td>Drum-core</td><td></td><td></td></tr>
<tr><td>Drum-core</td><td>0,86945</td><td>0,057</td><td><0,00001</td></tr>
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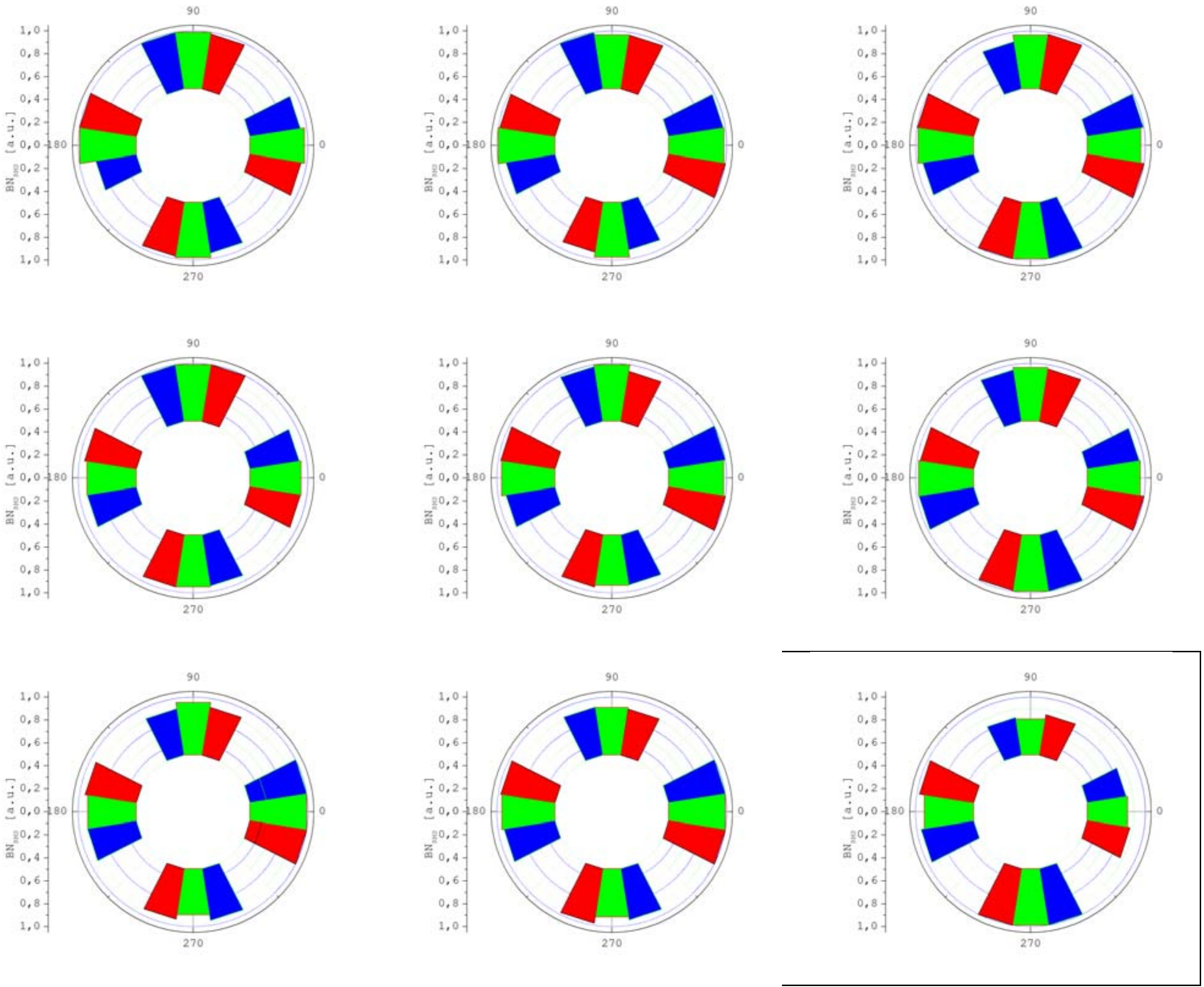


Fig. 15 Normalized values of $BN_{RMS}$ in measurement points on the steel sheet sample; red – air coil, green - pot core coil, blue – drum core coil

**Conclusions**

Three constructions of the Barkhausen noise sensors were investigated in different kind of tests. In all of these studies, the magnetizations conditions as well as the parameters of conditioning unit were the same for each of the sensor.

Superficial comparison of the obtained results, for example shapes of the magnetization characteristics, allows to state that observed differences were rather quantitative than qualitative, due to different number of turns and presence or not of the core.

Performed statistical testing, revealed that differences can be significant in terms of measurement's resolution and among the tested sensors, the air coil had the most averaging property.

Therefore, be desirable to develop universal set of the calibration standard and procedures to the characterization of the measurement sensitivity and resolution of the Barkhausen sensors. This would allow compare the results of different scientific studies or industrial measurements.

***Acknowledgments***

*This study was carried out under principal research project No. BS/PB-201-301/2013*

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