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The influence of product thickness on the measurements by Barkhausen Noise method

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Properties

ABSTRACT

Purpose: The aim of this paper is to show how varying cross section thickness of tested product and calibration sample can depend on results of the residual stress measurements by the Barkhausen Noise method.
Design/methodology/approach: The Barkhausen noise parameters as RMS value and total number of Barkhausen pulses in samples with different thickness was measured and compared. Also influence of the frequency and intensity of the magnetization current was analysing.
Findings: The significant indirect influence of various cross-section thicknesses on Barkhausen Noise level was pointed. The equations describing influence of the thickness on Barkhausen noise at different magnetization current parameters were found.
Research limitations/implications: Also the influence of the differences in width of the calibration sample and tested product was observed but in this research was not analysed.
Practical implications: Taking into consideration obtained results lets compensate analytically indirect influence of geometrical factors and magnetization parameters on Barkhausen noise parameters.
Originality/value: Original value of this paper is demonstrating significant source of error during residual stress measurements by Barkhausen method. For this moment this fact were not taken into consideration.
Keywords: Non-destructive testing; Barkhausen method; Residual stress

1. Introduction

Empirical method of the residual stress determination can be divided into two groups: destructive and non-destructive [1-2]. In opposite to laboratory time–consuming destructive method, the non-destructive method are the answer to industry demand, searching quick and easy way to estimate residual stress without damaging of the tested product. At the present time the most used methods are ultrasonic and portable X-ray systems. Besides, the modern and progressive is Magnetic Barkhausen Noise method [3-5]. Moreover, for microstructure inspection of the steel the Barkhausen method is used too [6-8].

Generally, this method is based on the physical phenomenon proceeded in ferromagnetic materials during magnetisation. It is known that cyclic change of external magnetic field is causing irreversible movement of the Bloch walls (Barkhausen jump) and periodic rebuilding and resizing of the magnetic domain structure. Course of this phenomenon is determined by a lot of materials properties as internal stress or crystal defects [9-10]. Discontinuous domains wall motions appear in local disturbance of the magnetic induction inside tested material and can be measured by special equipment.

An idea of the stress measurement by this method depends on comparison of the one of the Barkhausen noise (BN) parameter measured in investigated material with calibration curve in bending test obtained. The tensile stress increases BN intensity and compressive stress decreases it [11].

Beside of material's properties, also whichever magnetization modifications have great non-linear influence on BN noise level [12]. One of the magnetization change's sources is fact that in most cases, the investigated product's cross-section area is much bigger than one of the sample used for calibration. It is important because with area's changes the induction and magnetisation field intensity in sub-surface area are varying too.

It seems that for this moment, in many cases this fact were not often taken into consideration during measurements doing by the Barkhausen method. It follows from the reason that direct measurement of the magnetizations state inside of the investigated materials is very difficult.

Moreover, also using in this purpose the numerical modelling of magnetic field and BN model have a lot of limitations because of many simplification assumed for simulation [13-15]

The aim of this work was to find a real relationship describing indirect influence of the calibration sample and tested material thickness' differences on BN parameters, by the magnetic field intensity change. The experiment was planned as the series of the measurement of BN parameters in samples which physically modelled the products with varies thickness.

2. Description of the research

2.1. Instrumentation

The measurements of the Barkhausen noise parameters were done with elaborated apparatus [16], that appearance was presented in Figure 1. It consists of three independent parts: magnetization, Barkhausen signal conditioning and BN processing unit.

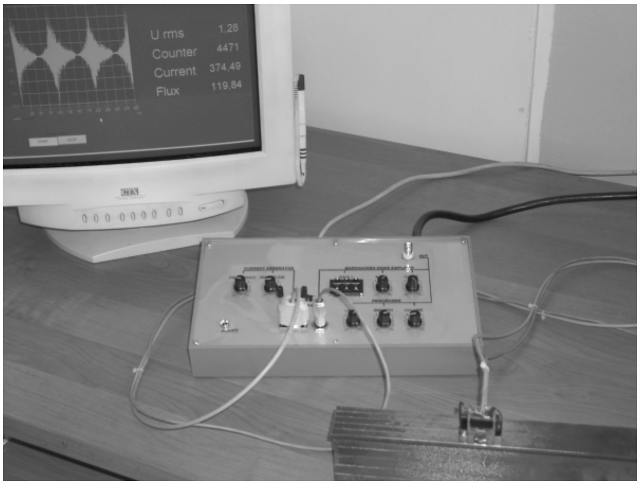

Fig.1. A view of equipment for BN measurements

The magnetization part includes frequency tuned triangular wave RC oscillator and voltage to current converter. The one task is to supply current for excitation coil, which is magnetizing tested material. A low raw Barkhausen signal, is picked up from subsurface region by the measurement coil and next is amplifying and filtering in conditioning unit. The parameters of the BN: root mean square (RMS_{BN}) value, number of Barkhausen pulses and amplitude are determined in signal processing unit. The PC computer with PCI 1711 data acquisition card was used for further data converting and visualisation.

2.2. Samples

For experiment up to five samples – flat bars were used. They were assembled in to the pack to simulate physically different thickness of the investigated product. The samples were cut off from commercial flat bars made from S235JGR2 steel. The one has dimension: 90×20×5 mm. The surfaces of the samples were polished to obtain as good as possible contact between them. Only the surface of the one sample was not preparing to avoid introduction of the residual stress or microstructure changes and keep the contact condition as in the real measurements

To maintain stable experience's conditions the measuring heads was attached to one's sample surface presented in Figure 2. It let avoid of the Barkhausen noise changes caused by different of microstructure or residual stress state in each of the samples.

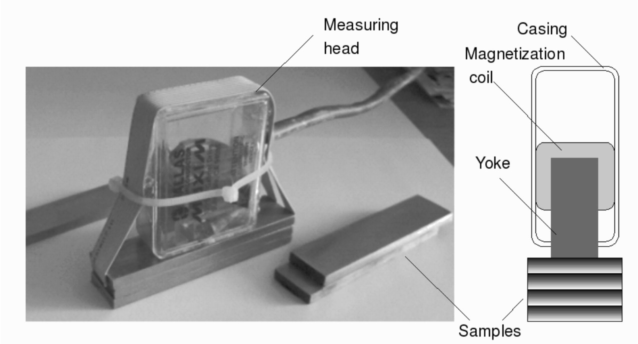

Fig. 2. Details of the experimental set-up

2.3. Experiment

The experiment on BN parameters level measurement in different thickness block of the samples was relied. The thickness was changed form 5mm (comparable to calibration sample) to 25 mm (five samples – comparable to heavy structural beam).

The investigations were made at different magnetisation condition. At first, the value of the magnetisation current was maintained at 200 mA and the following frequency was used 3 Hz, 6 Hz, 12 Hz, 22 Hz and 38 Hz Next, keeping the constant frequency $f_m = 12$ Hz, the measurements were made for six values of the magnetisation current I_m, between 180 mA and 340 mA.

During the experiment, the RMS value and number of Barkhausen pulses were measured.

3. Results

In Figure 3 was shown example of the initial investigations - dependence of the RMS_{BN} in function of the sample thickness. It is explain general relationships between them.

The necessary relative current change I_m/I_{m0} for thickness changes compensation in Figure 3 was presented too. As can be observed, to maintain the same magnetization conditions in product of 25 mm thickness as in 5 mm calibration sample, the magnetisation current I_m must be corrected and increased about 40% to initial value I_{m0}

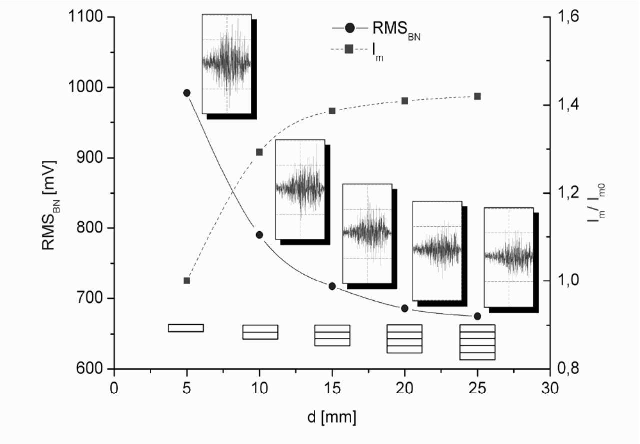

Fig. 3. Relationship between simulation product's thickness d and BN level and magnetization current correction

Detailed results of the first part of the experiments, involved investigation of the magnetisation frequency f_m, were shown in Figure 4. The changes of RMS_{BN} in function of thickness d, for better visibility, were shown as relative values.

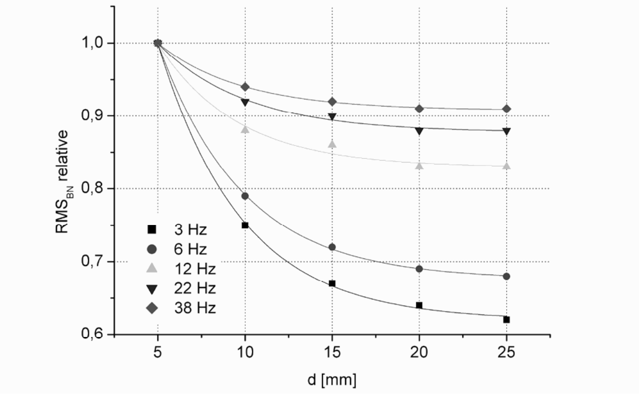

Fig. 4. Influence of thickness d on relative changes of RMS_{BN} at different frequency of magnetization f_m

These changes can be approximated by the exponential function given by equation (1) and are most significant up to 15 mm thickness.

$$RMS_{BN} = a_0 + a_1 \cdot e^{\left(\frac{-d}{t_1}\right)} \tag{1}$$

The values of the coefficients a_0, a_1 and t_1 were collected in Table 1. They were evaluated by using ORGIN software. In the table also value of the data-fitting ratio R^2 was placed

Table 1.
Coefficients of equation (1) for const magnetization current

f_m [Hz]	a_0	a_1	t_1	R^2
3	0.61926	1.07937	4.79153	0.99863
6	0.67562	0.90522	4.86811	0.99966
12	0.82157	0.46877	5.13298	0.97369
22	0.87737	0.32861	5.05443	0.98904
38	0.90764	0.26213	4.79298	0.99842

Analyse of the presented on chart curves' courses let show significant influence of the magnetization frequency, according to known theoretical formula (2), describing the depth of electromagnetic field penetration d_z, as the effect of eddy current

$$d_z = \frac{1}{\sqrt{\pi \cdot f_m \cdot \mu \cdot \gamma}} \tag{2}$$

where: μ - magnetic permeability and γ - electrical conductivity of the tested materials

Considerable influence of the thickness changes proceeds only up to smaller value than depth d_z. and strong depend of frequency f_m: the depth of magnetic field penetration for the lowest frequency is greater than for higher. For this reason, the effective cross section area inside sample, where the magnetic flux produced by magnetisation yoke is closing; with frequency change is varying too. To make an assumption that widths of samples and the magnetisation flux produced by magnetisation yoke are constant, the magnetic field H_m intensity in the investigated sample is in reverse proportional to the one. If the cross section area is smaller than effective cross section of the magnetic flux way (for example in thin calibration sample), the H_m value is growing and bigger than in thicker one (e.g. in structural H-shape). It explains source of the BN changes course, caused by differences in the thickness and not materials properties.

The results of the RMS_{BN} measurements in function of the thickness d, obtained for different values of the magnetization current I_m, were presented as the charts and shown Figure 5.

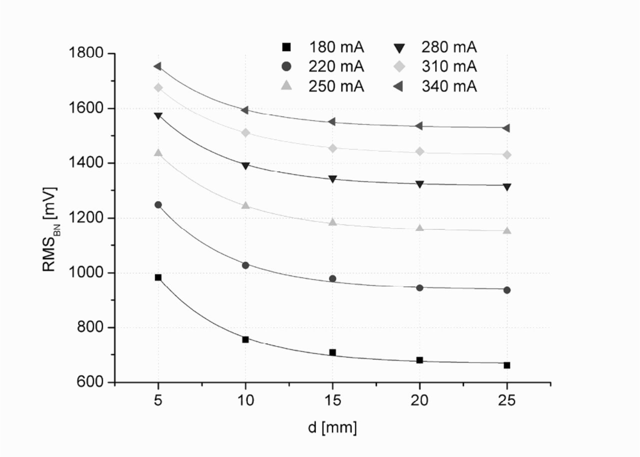

Fig. 5. Influence of thickness d on RMS_{BN} value at different magnetization current I_m

The character of changes of the RMS_{BN} for each value of the magnetization current are similar and can be approximated also by exponential function (1), with coefficients in Table 2 collected.

Table 2.
Coefficients of equation (1) for const magnetization frequency

I_m [mA]	a_0	a_1	t_1	R^2
180	667.63490	1043.1595	4.17935	0.99183
220	937.80241	1002.98564	4.25031	0.99388
250	1148.11238	855.14224	4.57504	0.99969
280	1316.04284	849.89411	4.21604	0.99859
310	1429.69920	744.34938	4.50479	0.99840
340	1527.52831	737.30406	4.20030	0.99897

Similar, exponential dependences were observed and presented on chart in Figure 6 for second measured parameters N_C – number of the counts of the Barkhausen jumps in one period of the magnetisation,.

It follows from the analysis of both presented charts that the change of the BN parameters was smaller at higher values of magnetization current I_m. This result very good corresponds with characteristic, sigmoid dependences of the BN in function of the magnetisation (magnetic field intensity), described in [12].

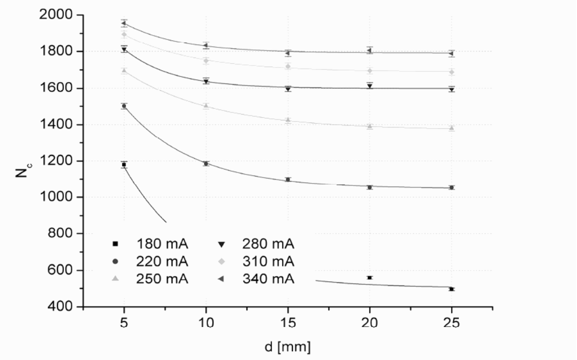

Fig. 6. Influence of thickness d on number of counts N_c value at different magnetization current I_m

The experiment described above, was repeated by using narrowed six millimetre-width samples. The obtained results has the same qualitative character but significantly quantitative different. It creates implication to investigate influence of width's difference between calibration samples and tested product too. Results of these will be present in further works.

4. Conclusions

On the base of the results obtained during experiment can be concluded that influence of the difference between thickness of the calibration sample and tested product on BN are significant and must be taken into consideration necessarily and compensating [17] Otherwise, received result of the residual stress or the other materials properties measured by the Barkhausen method can be estimated with considerable error. Revealed during the studies, influence of the magnetisation frequency and current intensity lets state that using of relative higher frequency and bigger values of the magnetization current allows minimize this error. On the other hand, lower frequencies of magnetisation lets determine residual stress or other investigated materials properties from deeper layer [18]. Moreover the measurements done with the smaller values of the magnetisation current are more sensitive. For these reasons, the better way is to compensate disadvantageous influence of the described thickness differences than using no effective magnetisation values.

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