Non - destructive Analysis of Ferromagnetic Materials by Means of Barkhausen Effect Methods

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***Abstract*— The paper presents two modern methods based on the effect of Barkhausen and used for the study of specimens of construction steel and amorphous alloys. In particular, the methods discussed in the study are the method of magnetic noise and that of magneto-acoustic emission. The study deals with the effect of steel and amorphous alloys structure on the numerical characteristics of the magnetic noise (magnetic noise stress) and on those of the magneto-acoustic emission (mean quadratic stress of the acoustic emission). A possibility to apply those characteristics is outlined, i.e. one can use them when performing specific non-destructive control of constructional steels and amorphous alloys. It is proved that the signals of the magnetic noise stress and those of the magneto-acoustic emission depend on the magnitude of the structure of the studied construction steels and amorphous alloys.**

***Keywords*— Magnetic noise voltage, Magneto-acoustic emission**

I. Introduction

The methods of magnetic Barkhausen noise (BN) and Barkhausen magneto-acoustic emission (MAE), based on the Barkhausen effect, are used for non-destructive testing of structure and mechanical properties of ferromagnetic materials [1, 2, 5, 7]. The presented work is intended to study the applicability of magnetic noise and the characteristics of magneto-acoustic emission - magnetic noise voltage U_{BN} of magnetic noise and root mean square voltage U_{MAE}, of magneto-acoustic emission for non-destructive testing of internal voltages in samples with volumetric plastic deformation and for non-destructive testing of the structure of samples of amorphous alloys with different composition and structural defects [6, 8, 9, 11].

The Barkhausen effect consists in the fact that when a ferromagnetic material is magnetized by an external magnetic field, it is accompanied by numerous jumps in the magnetization. These jumps are due to the jump-like displacement of the domain boundaries of the ferromagnet. The disorderly superposition of magnetization jumps occurring during cyclic remagnetization of the ferromagnetic material causes the emission of clusters of electromagnetic waves, which are called Barkhausen (NB) noise, and also acoustic waves, which are called magnetoacoustic emission (MAE). Magnetic noise characteristics are measured with an inductive receiver coil, and magnetoacoustic emission with a piezo sensor. To study the Barkhausen effect, a setup was created to measure the non-destructive informational characteristics of magnetic noise and magnetoacoustic emission in ferromagnetic materials. It has been shown that the characteristics of the Barnhausen effect can be used to study the structure and mechanical properties of 40X structural steel specimens. In fig. 1. the basic block diagram of the equipment for measuring E_{BN} and E_{MAE} is shown:

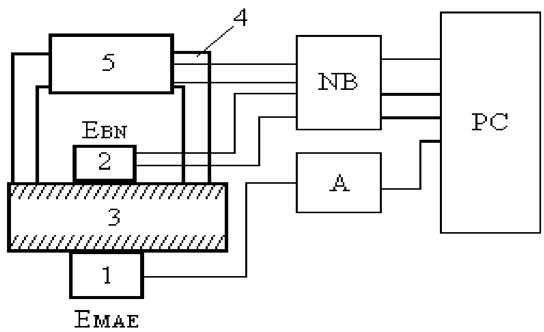

Fig. 1. Block diagram of the device for measuring EBN and E MAE

The tested sample 3 is uniformly pressed by the electromagnet 4 with the magnetizing coil 5 between the coil 2 and the piezo sensor 1. The electromagnet 4 creates an alternating magnetic field that cyclically magnetizes the sample. Magnetic noise occurs in it, which induces pulses of magnetic noise voltage in the measuring coil 2. In addition, magnetostrictive deformation of the domains also occurs. They cause acoustic waves with a frequency of over 100KHz in the material. These waves are converted into electrical pulses by the piezo sensor 1. The two signals are processed and the informational non-destructive characteristics E_{BN} and E_{MAE} are determined. (fig. 1) .

Measured values:

- Average - square value of the noise voltage in the frequency range (8-100) KHz: - E_{BN}, mV;

- Average value of the noise voltage for a certain frequency band: E_{BN} (f), mV;

- Mean-square value of the magneto-acoustic emission voltage: E_{MAE}, mV;

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II. MATERIALS AND METHODS

A. MATERIALS

Samples of 30Cr2MnA2F steel with a rectangular cross section (10x4)mm and a length of 100mm were used for the test. The specimens were subjected to plastic deformation at a temperature of 900 °C. Their degree of volumetric plastic deformation varies from 10% to 60%. All test specimens were analyzed by X-ray diffraction analysis to quantify the internal micro-stresses. Amorphous Fe-based alloys of the $(Fe_xNi_{1-x})_{80}B_{20}$ system were used to prepare test specimens, which were then super-cooled in a 50µm thick strip [3]. The identification of the structure was made by X-ray and metallographic analyzes (Table 1).

TABLE I. STRUCTURE AND COMPOSITION OF AMORPHOUS ALLOY SPECIMENS

Group	Composition	Structure	Dimensions (mm)
1	1st	Amorphous	13 x 100
2	1st	Presence of crystal grains	13 x 100
3	2nd	Amorphous	15 x 100
4	3rd	Amorphous with pores	13 x 100

B. EQUIPMENT

Figure 2 shows a block diagram of the equipment for testing test specimens. The test specimen 3 is placed between the magnetic core 4 and the piezoelectric transducer 1. The low frequency sinusoidal voltage is applied to the magnetizing coil 5 and through the magnetic core 4 cyclically magnetizes the area of the specimen 3 located between the poles of the electromagnet.

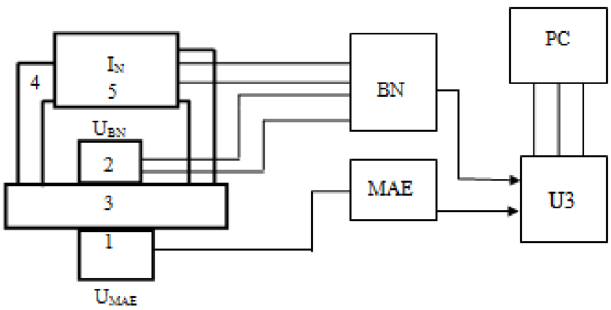

Fig. 2. Block-diagram of BN and MAE measuring apparatus

Symbols used:

BN - magnetic noise;

MAE - magneto-acoustic emission;

U_{BN} - magnetic noise voltage (µV);

U_{MAE} - rms voltage of magneto-acoustic emission (µV);

I_N - magnetizing curent (mA);

σ_i - internal stress (MPa).

C. METHOD OF MEASUREMENT

BN and MAE are induced in the magnetization zone of the sample. BN generates voltage pulses U_{BN} in the receiving winding 2, which are sent to the BN unit for processing. MAE signals are also converted from the piezoelectric transducer 1 into electrical pulses, which are then sent to the AE (acoustic emission) amplifier to convert them to U_{MAE} voltage. Particular attention is paid to the calibration and metrological provision of the examination equipment [10,12].

From the BN and MAE blocks the signals are sent for analysis from a personal computer through a module for data collection and processing - LabJack (U3). The optimization of the measurement was performed using LabVIEW software. Applications written in LabVIEW are called virtual tools. LabVIEW measurement data can be visualized and evaluated [11]. The characteristics measured by this virtual system are the magnetic noise voltage U_{BN}, the rms voltage U_{MAE} of the magneto-acoustic emission and the dependences $U_{BN}(I_N)$ and $U_{MAE}(I_N)$.

III. RESULTS AND DISCUSSION

Figure 3 shows the dependences of U_{BN} and U_{MAE} on the internal stresses of steel specimens at magnetizing current I_N = 100 mA. Analysis of the data shows that the density of BN in the range of internal stresses decreases when they increase to 600MPa, while MAE decreases almost linearly with increasing stresses. It is probable that the increase in the degree of plastic deformation leads to an increase in the dislocation structure of the material, whereby the irreversible movements of the magnetization of the 90° domain boundaries gradually decrease. As the intensity of the magnetic field H increases, the processes of movement of the 180° domain boundaries increasingly shift towards the movement of the 90° domain boundaries and rotation [1, 4].

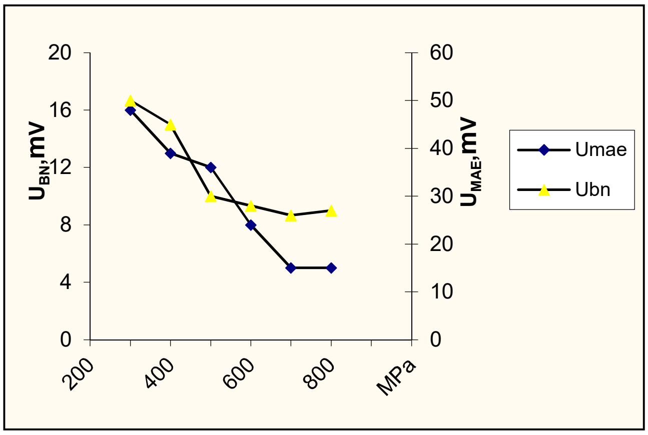

Fig. 3. Dependences of the internal voltages U_{BN} and U_{MAE} on magnetizing current I_N = 100 mA

This phenomenon is in agreement with the results for the $U_{BN}(I_N)$ and $U_{MAE}(I_N)$ dependencies shown in Figure 4, where curve 1 refers to the values of the internal stress σ_i - (300-350)MPa, curve 2 refers to σ_i - (400 -450)MPa and curve 3 refers to σ_i - (600-700)MPa.

Figure 5 shows the U_{BN} (I_N) and U_{MAE} (I_N) characteristics for the groups of amorphous samples in Table 1. The solid lines refer to U_{BN} (I_N) and the dashed lines refer to U_{MAE} (I_N). U_{BN} (I_N) dependencies are in the frequency range of U_{BN} (8-

100) kHz, and U_{MAE} (I_N) dependencies are from (5 - 150) kHz. One can see very large U_{BN} values that go beyond the amplifier's range [11].

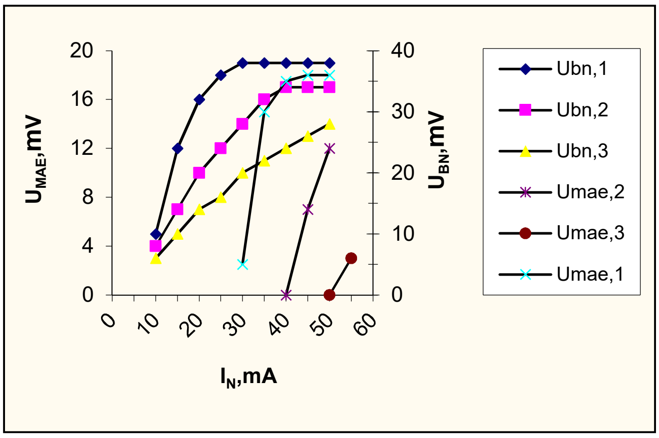

Fig. 4. Characteristics of U_{BN} (I_N) and U_{MAE} (MAE) of construction steel with increasing the magnetizing current I_N from 0 to 60 mA

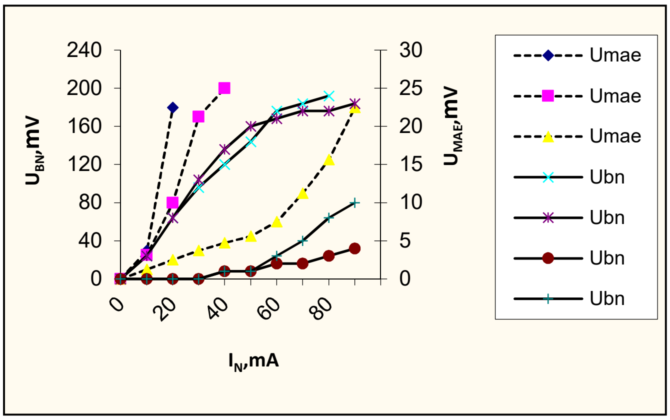

Fig. 5. Dependencies of $U_{BN}(I_N)$ and $U_{MAE}(I_N)$ of amorphous alloys on the magnetizing current I_N, mA

Figure 6 shows in more detail the U_{BN} (I_N) characteristics for discrete frequencies of noise voltages (25, 35 and 45) kHz for composition №3 of Table 1.

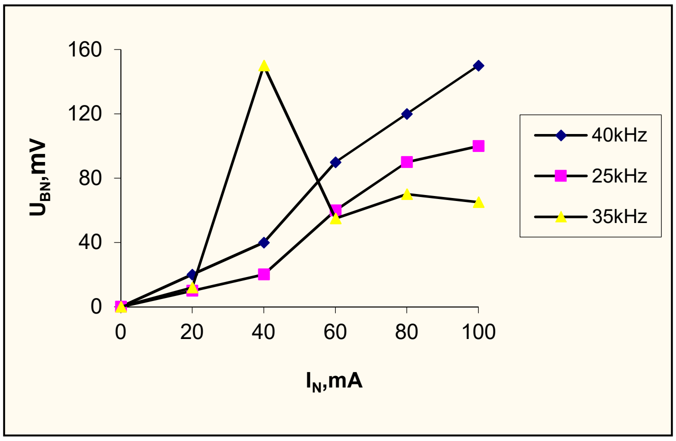

Fig. 6. U_{BN} (I_N) characteristics in an amorphous alloy for discrete U_{BN} frequencies

IV. CONCLUSIONS

The experimental results of the analysis confirm the fundamental differences between the characteristics of BN and MAE, although both phenomena are induced by the same source based on the abrupt irreversible movement of the domains boundaries under the action of an external magnetic field.

The characteristics of U_{BN} and U_{MAE} can be used for non-destructive analysis of internal stresses in structural steel subjected to bulk plastic deformation. In this case, the non-destructive information feature of U_{MAE} is more appropriate for the study.

These characteristics can be used in the non-destructive study of the structural state of amorphous alloys based on Fe, where defects such as the presence of crystal grains, pores, dislocations and others are unacceptable.

The graph in Figure 6 shows an unexplored phenomenon. At a certain discrete frequency of 35kHz there is an extreme at a certain level of magnetizing current. This phenomenon is characteristic and different for each alloy with different amorphizing elements [11]. Probably these effects are related to internal friction and chemical composition of ferromagnetic amorphous alloys [4]. Further research will be done to clarify the origin of the phenomenon.

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