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Comparison Between Different Experimental Set-Ups for Measuring the Magnetic Barkhausen Noise in a Deformed 1050 Steel

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Abstract The magnetic Barkhausen emission is investigated in deformed ANSI 1050 steel samples using four experimental configurations. These configurations vary according the type of magnetization (solenoid or yoke) and the recording the magnetic signal (bobbin above or around sample).The level of total strain was 0.4, 0.8, 1.0 and 3.0%. In all cases the same monotonous decrease dependence of emission magnetic with strain was obtained, showing that the four configurations give similar results. However, the yoke–pancake configuration was the most sensitive.

1 Introduction

In the last decade, the magnetic Barkhausen emission (MBE) has become awidely used non-destructive technique for the characterization of ferromagnetic materials undergoing structural changes and residual stresses. The high sensitivity of MBE to changes allows one to obtain information about

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the material behavior under real stress, which is an advantage of this characterization method.

Many examples of the application of MBE application can be found in the literature. It is a fast, cheap and practical characterization method for non-destructive testing [1–10].

MBE may be caused by applying magnetic fields to the ferromagnetic material: periodic in time, sliding or rotational [11]. In this paper we analyze the magnetization of the material through periodic magnetic fields in time, which has been the most commonly used method in literature.

The measurement setup used in the above reports [12,13] differs in the way the magnetic field is generated and in how the Barkhausen signal is captured. Applying a periodic magnetic field time, the magnetization of the material is achieved: using either an air core and or a yoke of ferromagnetic material. Both methods allow measuring the MBE in magnetic materials.

Similarly we find two methods of capturing the MBE signal. The first uses a coil wound around the sample, measuring the MBE of all the material within the signal coil. A second configuration employs a coil located on the surface of the material. This arrangement primarily records the MBE signal of the surface contacting the coil.

From the above, there are four possibilities of selection of the experimental setup for the characterization of MBE as shown by several authors [12–15]. Any combination of setup allows the characterization of the material. However, there are sometimes differing views of the effectiveness of the setup used in Barkhausen signal characterization. As further discussed, for the yoke–pancake configuration the coil was able to detect more clearly the signal produced by this magnetic circuit. The current study presents an analysis of the MBE measured with four possibilities of experimental setup. The obtained signal has particularities, according each configuration.

2 Experimental Setup

Experimental measurements were conducted on samples of cold-rolled annealed AISI 1050 steel sheets (25 mm × 250 mm × 1 mm) having a chemical composition according to Table 1. All samples were cut along the steel sheet rolling direction. Afterwards, samples were subjected to a strain rate of approximately 0.5 mm/min, by means of an uniaxial stress–strain testing machine, which produced total strain of 0.4, 0.8, 1.0 and 3.0%, on the a aforementioned samples. Measurements were carried out on samples prior to and after the additional deformation process.

The experimental setup used in the magnetic Barkhausen measurement uses a variable magnetic field in time. It consists of two measuring modules: magnetic excitation signal and recording the measurements signal. MBE were performed by an experimental setup shown in Fig. 1.

The magnetic excitation module consists of an Agilent 33210A generator signal and a Kepco BOP 20-20M bipolar source governed by control software. The magnetic signal generated by this circuit is applied to the magnetic field generator, which may be an air core coil or yoke magnetization. Measurements were made by using a sinusoidal magnetic wave of 10 Hz. The MBE signal was detected using a magnetic coil. The MBE sensor output was amplified and band pass filtered (1–150 kHz). The applied sampling frequency was 300 kHz. A National Instruments card was used for measuring the Barkhausen emission and dedicated software was developed for processing and storing the time signal of MBE. The magnetizing system, sensor coil and samples were placed in a grounded steel box to reduce environmental noise.

In this work, the MBE_{rms} response is always the root mean square (rms) value of the noise and is referred to as rms voltage. By defining a bottom voltage level, the noise not belonging to the Barkhausen signal was eliminated from the MBE_{rms} measurements. This threshold is determined by taking a time window with the background noise only and, then, calculating the rms of this noise. Only those MBE_{rms} voltages having amplitude higher than this threshold are considered for analysis. This magnitude is first calculated for 10 MBE_{rms} measurements of each sample and then averaged.

In the performed measurements a solenoid coil 700 turns (AWG 18) with a cross section of 1200 mm^2, as well as a yoke of FeSi with a drive coil 400 turns (AWG 22) and core cross section of 225 mm^2 was used .

The coils used for MBE registration were of two types. A coil wound on a support of cross section of 31 mm^2 in 1000 turns of copper wire AWG 44. This coil allows the sample be placed in such a way that the all magnetic flux emitted by the sample is recorded inside coil. The pancake coil, which measured the normal component of the MBE_{rms} signal, was constructed by winding copper wire (AWG 44) around a small cylindrical plastic bobbin with cross section of 58 mm^2. The number of turns used was 2000. This coil is placed between the feet of a core FeSi used as magnetizer.

Figures 2, 3, 4, and 5 show the four combinations of the magnetization form and the sensor coil signal corresponding to magnetic emission in AISI 1050 samples.

All configurations used the same magnetic circuit and the same magnetic excitation circuit. The most notable difference in the set-ups is due to number of turns in the coil and magnetization field. The Barkhausen measurement is qualitative and the setup choice may vary considerably for each laboratory. This is not standardized. For example, a coil may have different number of turns, different diameter of wire, and different width.

Table 1 Steel samples composition (10^{-3} wt%)

AISI	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Ti	Nb
1050	517	686	15.7	4	195	42.2	13	15.1	8.7	1.3	1.8	1.9

Fig. 1 Experimental arrangement for magnetic Barkhausen measuring
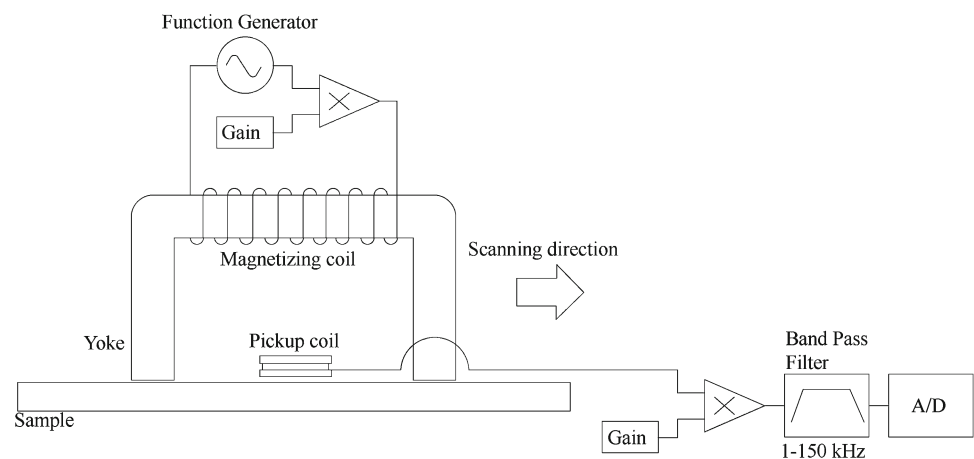
Fig. 2 Setup: coil–coil
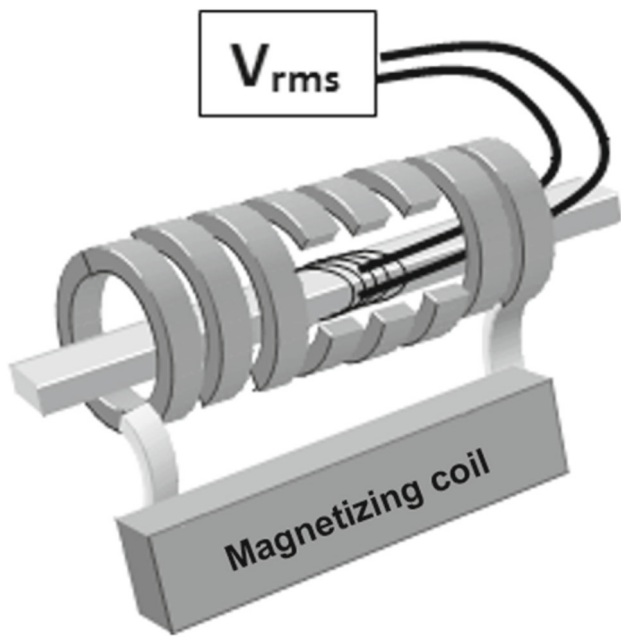
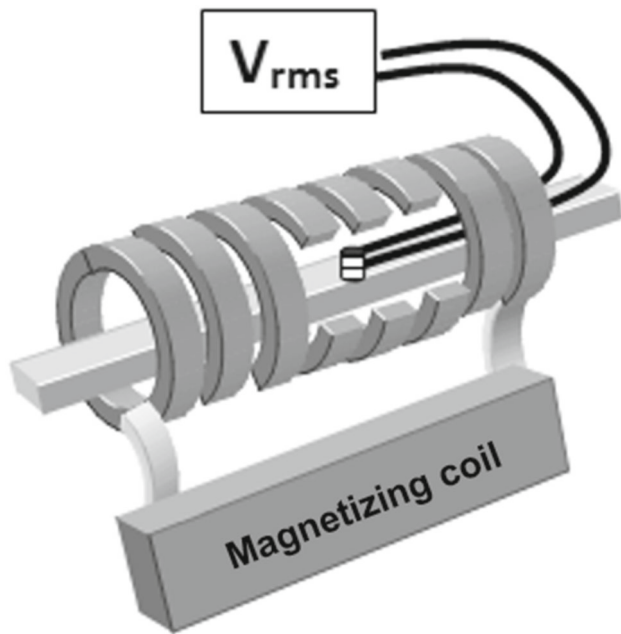**Fig. 3** Setup: coil–pancake

Fig. 4 Setup: yoke–coil

Fig. 5 Setup: yoke–pancake

3 Results and Discussion

Figures 6, 7, 8, and 9 shows the MBE_{rms} envelope behavior of the samples AISI 1050 with different total strain, mostly plastic, for the four combinations employed. They show similar behavior between MBE_{rms} and the total strain. The MBE_{rms} decreased with increasing deformation in the samples.

Most of the MBE_{rms} signal comes from the surface, because the magnetic circuit is closed near to the surface.
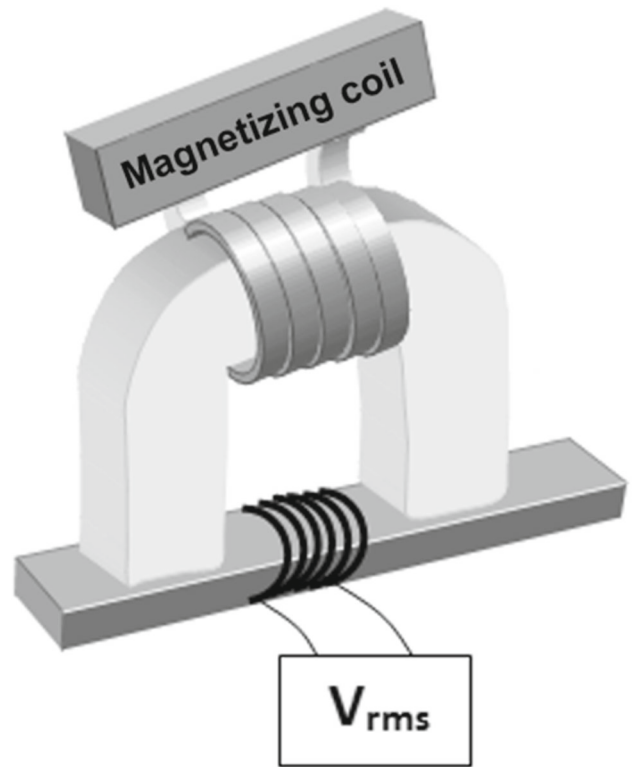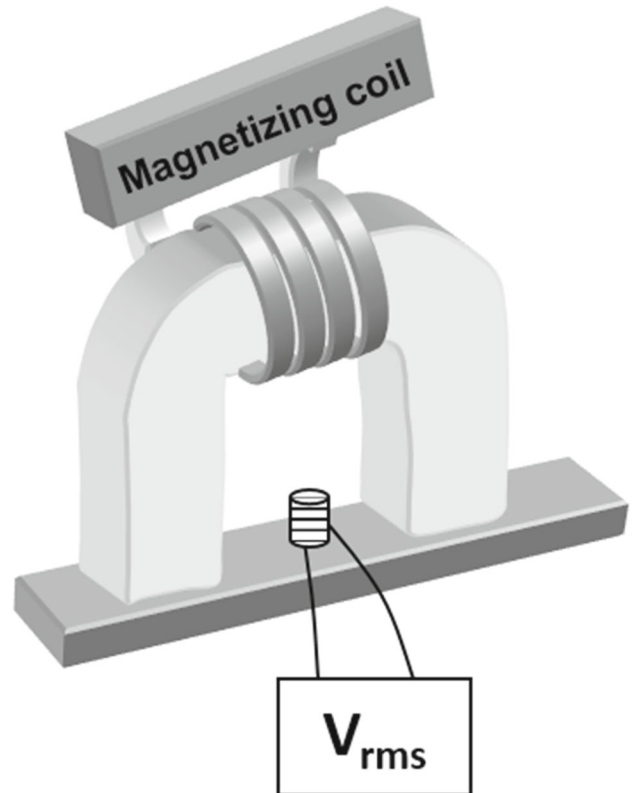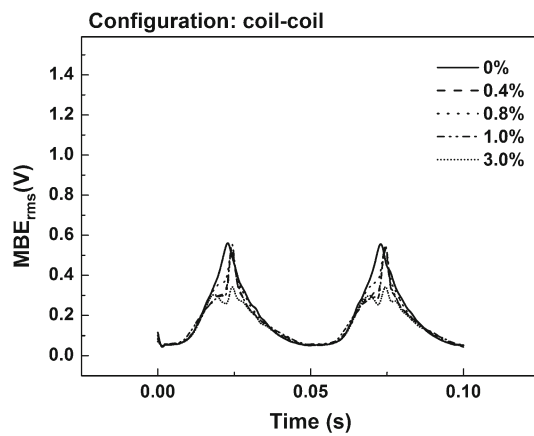
Fig. 6 Behavior envelopes magnetic Barkhausen emission for coil-coil configuration
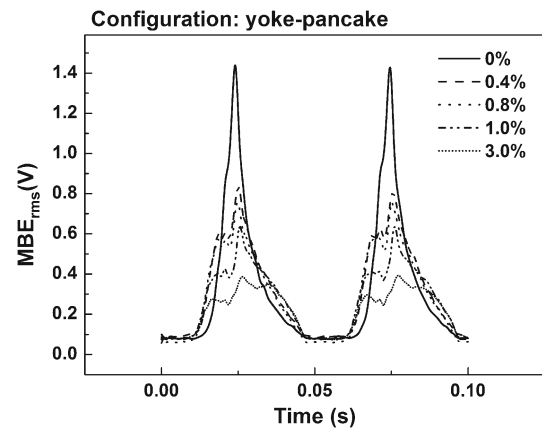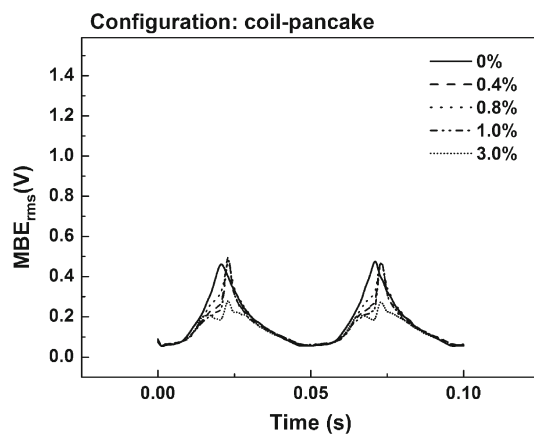

Fig. 7 Behavior envelopes magnetic Barkhausen emission for coil-pancake configuration

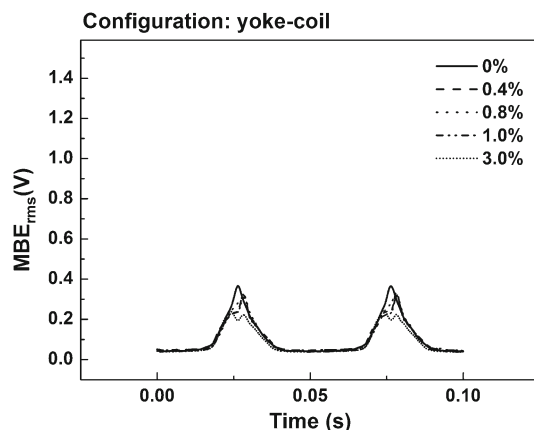**Fig. 8** Behavior envelopes magnetic Barkhausen emission for yoke-coil configuration

Fig. 9 Behavior envelopes magnetic Barkhausen emission for yoke-pancake configuration

Thus, the yoke–pancake seems to be more sensitive, as can be seen in Figs. 6, 7, 8, and 9. As the Barkhausen signal is usually weak, and difficult to separate from background, the strongest signal gave a result able to be a reference. This signal of the other configurations corroborate the results obtained with the yoke–pancake configuration.

As can be seen in Figs. 6, 7, and 8, the envelopes at the MBE_{rms} signal present similar shapes and magnitudes in the samples analyzed. In Fig. 9, it more clearly observed that the yoke–pancake configuration gives more intense signal. The wave the envelope shape shows the same trend for all other configurations of measurement, as also observed in Fig. 9.

Figure 10 shows the Barkhausen magnetic emission in the frequency band 1–150 kHz for the different experimental configurations of the sensor coils corresponding to the sample without plastic deformation. Note in Fig. 10 a clear peak in the 90 kHz surroundings, corresponding to the yoke–pancake configuration. For the yoke–pancake configuration the coil was able to detect more clearly the signal produced by this magnetic circuit. Each coil has specific frequency of resonance, and peaks may appear for this frequency of resonance [16].

Figure 11 shows MBE_{rms} dependence with total strain corresponding to the four combinations of experimental setup used. In all experimental settings, it is observed the same monotonous decreasing behavior of MBE_{rms} with increasing stress. The yoke–pancake configuration gave the most clear signal, and the general trend was confirmed with all the other setups.

Figure 11 shows that the volumetric magnetic flux measuring corresponding to the use of a sensing coil around the sample is similar to flux emitted by the sample surface when
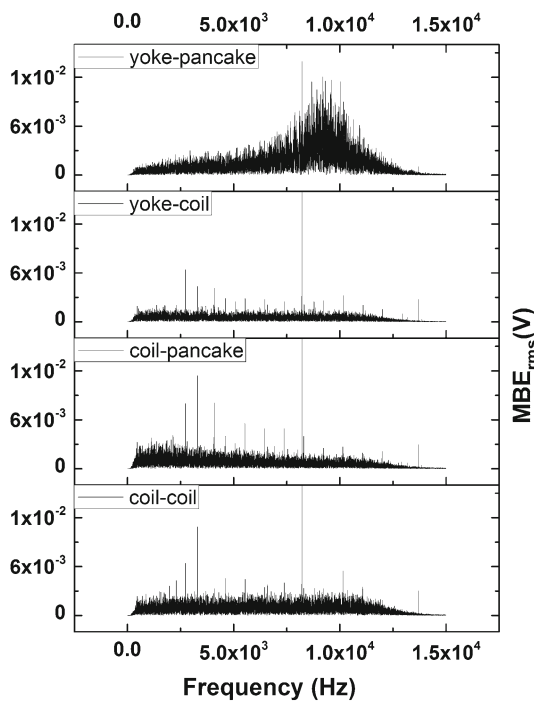
Fig. 10 Barkhausen magnetic emission in the frequency band 1–150 kHz for the different setup of the sensor coils corresponding to the sample without total strain
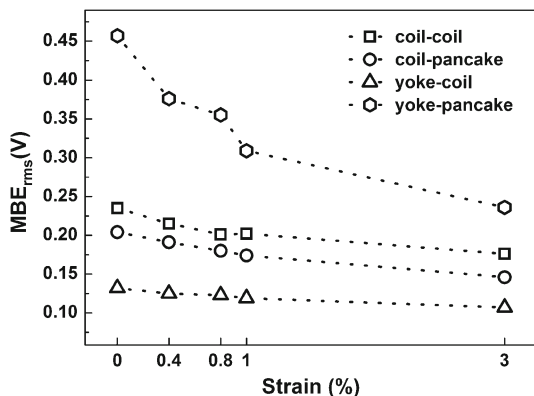

Fig. 11 Magnetic emission dependence based on the experimental setup used

a pancake coil is used over the sample. For all setups, the reproducibility is very good. Besides, the final result is average of ten measurements. That is, the MBE behavior has the same trend for all configurations.

This justifies the widespread use of geometry yoke–pancake, which also is presumably the most versatile in the characterization of ferromagnetic materials.

In all four setups, it is observed a monotonous decrease of MBE$_{rms}$ signal when the total deformation increased. In addition, the yoke–pancake configuration has a clear practical advantage. The MBE acquisition using the yoke–pancake

configuration is fast and can be used in field-test materials as simple non-destructive method.

The results of this study suggest that some standardization would be necessary for comparison between different results in literature.

4 Conclusion

This work presents experiments where MBE was measured using four experimental configurations corresponding to the shape of magnetization and the recording of the magnetic signal. In all four set-ups, it observed a monotonous decrease of MBE$_{rms}$ signal when the total deformation increased in AISI 1050 steel.In addition, the yoke–pancake configuration has a clear practical advantage. The yoke–pancake configuration is fast and suitable for field-test, evaluating materials as simple and non-destructive method.

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