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Analysis of the influence of some magnetizing parameters on magnetic Barkhausen noise using a microscopic model

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ABSTRACT

A microscopic model of magnetic Barkhausen noise (MBN) in carbon steel is proposed. The model uses the quasi-static magnetic formulation of Maxwell equations for electromagnetic fields combined with a microscopic model of the magnetic Barkhausen noise, and its equations are solved by means of finite difference formulation. The simulated MBN signal obtained presents high similarities to the measured MBN signal. Using this model, the influences of the uniformity and waveform profile of the excitation magnetic field on the envelope of the MBN signal were studied. The results show that the lack of uniformity of the excitation magnetic field increases the amplitude of the MBN envelope at the right of its main peak, and the waveform profile influences the shape of the MBN envelope. The proposed model can be used as a tool for studying the influence of several excitation parameters on the Barkhausen Noise in order to improve this technique.

1. Introduction

The magnetic Barkhausen noise (MBN) phenomenon is produced by discontinuous changes in the magnetization of ferromagnetic materials under the influence of a continuously variable magnetic field. These sudden fluctuations in the magnetization are caused by changes in domain wall's velocities as a result of their interaction with microstructural defects of the material. These defects depend on a variety of microstructure parameters such as grain size, carbon content, and residual stress, among others. Thus, the MBN signal contains information on a wide variety of microstructural and micromagnetic properties. This fact stimulates the development of MBN-based non-destructive applications for testing and evaluation of plastic deformation [1–2], grain size [3], and carbon content [4,5] in carbon steels.

Until now the MBN has mostly been used as a nondestructive method due to the correlation of some parameters of the MBN envelope such as its amplitude, rms voltage (V_{rms}), and shape, with the microstructure of the material [1–5]. However, there are some unsolved problems that should be addressed in order to increase the applications of the MBN as a non-destructive testing method. One of these problems is to separate in the MBN raw signal the influence of several microstructural parameters such as carbon content, plastic deformation, dislocations, and residual stress. Recently, some works have shown good results in this direction [6–9]. Another important issue to be considered is to find a method in order to take advantage of the high quantity of information contained in the MBN signal, and use that information for the characterization of soft magnetic materials. Nevertheless, in order to achieve this objective it is necessary to establish an accurate relationship between the parameters of the MBN signal measured by the sensor and the interaction between domain walls and the material's microstructure. This goal can be achieved by mean of MBN models. Several models of the MBN have been proposed with the intention to establish a correlation between the domain wall dynamic and the MBN raw signal. However, there are other elements playing important role in the MBN signal. One of these elements is the magnetization dynamics and its relation with the electromagnetic signal measured by the MBN sensor as well as the influence of the excitation parameters such as the amplitude, frequency, and the waveform profile.

Previous works have shown the influence of the magnetizing parameters on the MBN. Dhar and Atherton [10] analyzed the influence of the magnetizing parameters on the MBN. In particular they found that increasing the frequency of the AC magnetizing flux density increases the V_{rms} value of the MBN signal and a change in the shape of the distribution of MBN events. Jagadish et al. [11] analyzed the influence of the sweep rate (dB/dt) on the MBN. The results showed that the V_{rms}, the power spectral density of the MBN, increased proportionally to the sweep rate and the total number of MBN events and their amplitude. Also Mandache et al. [12] showed that the sensitivity of MBN to the applied tensile stress could be maximized using the appropriate amplitude of the

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excitation magnetic field. Bhattacharya and Vaidyanathan [13] revealed that the demagnetizing field could produce changes in the shape of the MBN envelope. The aforementioned works showed experimental evidences of the influence of the magnetizing parameters on the MBN. However, there is still a lack of theoretical explanations for these results. It has been shown in previous experimental works that the change of the waveform profile of the excitation magnetic field could affect the MBN signal [10]. Also, several works have analyzed the correlation between the parameters of the MBN envelope and the material properties. Thus, the change of excitation parameters such as the waveform profile and uniformity of the excitation magnetic field could affect the physical interpretation of these correlations. However, there are not theoretical studies correlating the influence of the excitation parameters on the MBN signal and how it affects the physical interpretation of the phenomena. Additionally, the actual excitation magnetic field inside the material should be estimated by extrapolations methods [14], which mean that, until now, there is no experimental way to estimate, directly, the influence on the MBN signal of the non-uniformity of the excitation magnetic field inside the samples under test. In this respect the simulation of the MBN taking into the account the distribution of the magnetic flux density inside the sample can be of great importance to study the influence of the non-uniformity of the excitation magnetic field.

The present study develops an electromagnetic model of the MBN which helps explaining the influence of the uniformity and the waveform profile of the excitation magnetic field on the MBN electromagnetic signal.

2. Materials and experimental setup

Measurement of MBN signals were performed using the experimental system developed by the authors. A block diagram of the experimental setup is shown in Fig. 1. The unit used for magnetizing the steel sample (a steel plate with 5×5 cm^2) and detecting the MBN is formed by an U-core of Fe–Si (differential permeability of $\mu' \sim 50{,}000$), an excitation magnetic field coil of 1000 turns, a pick-up coil (induction coil FS100/2 prove by MAGNET-PHYSIK) with an effective area $A_{ef}=112.7$ cm^2 and an array of three Hall effect sensors with a sensitivity of $S_H^1=1.97$ kA/m mV^{-1}, $S_H^2=1.12$ kA/m mV^{-1}, and $S_H^3=0.93$ kA/m mV^{-1}.

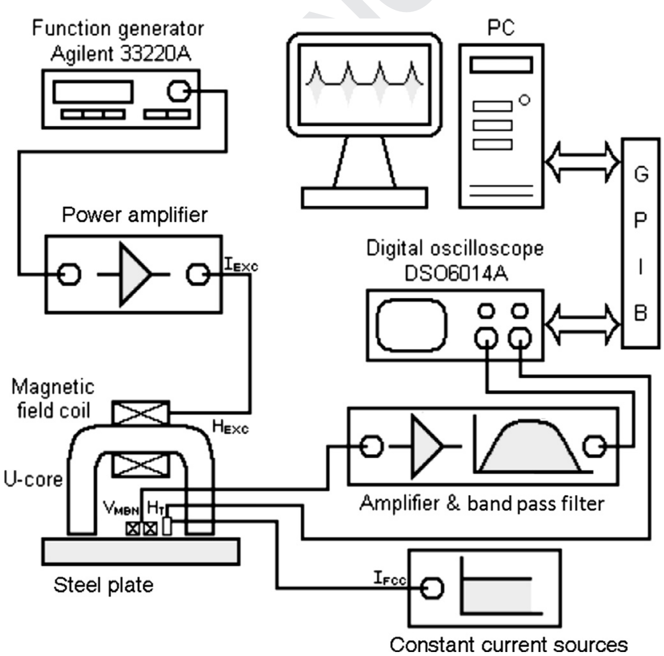

Fig. 1. Experimental setup.

A power amplifier supplies an alternating current up to 1 A to the excitation magnetic field coil, which generates the magnetization force applied to the sample through the U-core poles. The amplitude and frequency parameters of the excitation magnetic field are monitored using the Hall effect sensor array and these parameters are set by a function generator (Agilent 33200). The three Hall effect sensors are powered by three different constant current sources ($I_{FCC}=5.08\pm 0.02$ mA). The MBN signal is detected by means of the pick-up coil during the magnetization process. The output signal of the pick-up coil is fed to an amplifier with a gain (G) of 60 dB. The amplifier is connected to a band-pass filter with low cutoff frequency $f_c=1$ kHz to remove possible low-frequency interferences such as that coupled from the excitation coil and the 60 Hz, and high cutoff frequency $f_c=100$ kHz removes the high frequency harmonics. The output signal of the amplifier and the Hall effect sensors signals are fed into the four channels of the digital oscilloscope (Agilent DSO6014A), which is linked to a personal computer (PC). The oscilloscope sampling rate is 2 GHz but for the case of these MBN measurements is of 200 kHz due to the scaled time of the MBN signal. Both instruments are connected via GPIB interface for data collection and processing and a program developed in LabVIEW 8.2 under LINUX operating system controls the whole measurement process. The magnetic flux corresponding to the magnetic circuit, composed by the ferromagnetic core and the sample, is measured using the coil wrapped around one leg of the core.

A detailed view of the head probe composed by the MBN excitation-measurement elements is presented in Fig. 2.

The excitation of the MBN is produced by the variation of magnetic flux, induced by the excitation coil, in the magnetic circuit formed by the core and the sample. The magnetic flux follows a path represented in Fig. 2 as a dashed line. The pick-up coil, located in the middle between legs of the core, measured the flux rate on the sample surface by the Faraday induction law $\xi=A_{ef}\,dB/dt$ where A_{ef} is the coil effective area. A vertical array of Hall sensors was placed in the middle of the pick-up coil in order to measure three different values of the applied magnetic field for different distances from the sample surface in order to estimate the magnetic field intensity inside the sample by an extrapolation method reported in [14]. The system formed by the electromagnet and the sensors is mounted using an acrylic's fixer in order to avoid gaps and vibrations during measurements.

The simulated MBN signal presented in this work was obtained emulating the conditions of the experimental signal i.e., the sampling frequency of the simulation is equal to 1 MHz as in the experiment, which is equivalent to a time step $\tau=1\times 10^{-6}$ s in the simulations. The magnetic flux density, B, used to compute the

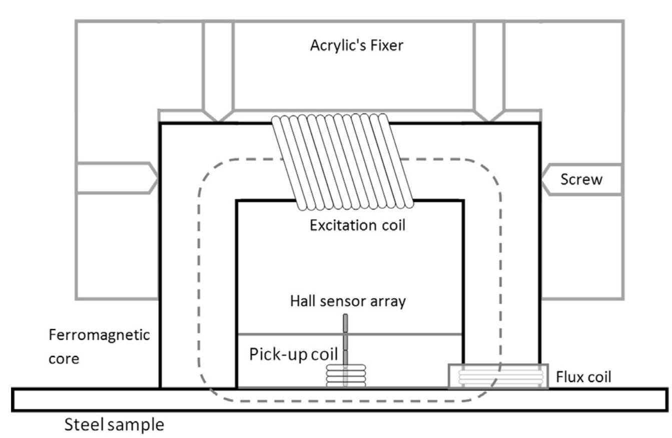

Fig. 2. Detailed view of the head probe of the MBN experimental setup. The head probe is composed by a ferromagnetic core wounded by the excitation coil, the pick-up coil, three Hall sensors, and a flux coil. These elements are fixed using an acrylic structure.

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