



An alternative method to remove excitation field interference from magnetic Barkhouse noise

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ARTICLE INFO

Article history:

Received 30 October 2013

Received in revised form

30 January 2014

Available online 3 March 2014

Keywords:

Magnetic Barkhausen noise

Electromotive force signal

Two-stage method

ABSTRACT

A simple method of measuring the magnetic Barkhausen noise (MBN) in two stages was tested. The purpose of the proposed method is to remove the excitation field interference from the induced electromotive force (EMF) signal without complex adjusting analog or digital filters before the measurement. In this method, two consecutive waveforms of the EMF signal were temporarily recorded, and then they were subtracted from each other in a software. Using this method we will obtain only the stochastic component of the EMF signal–MBN. The most common parameters of the MBN obtained by this method were studied. The experiments proved that with this method we are able to remove the dominant interference from the EMF signal in a wide excitation frequency range and thus we can simplify the measurement. Moreover, we found that the two-stage method is able to remove the interference signal without significant deterioration of the MBN even at the highest excitation frequency investigated, in contrast to the classical one-stage method.

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1. Introduction

The magnetic Barkhausen noise (MBN) measurement methods show good sensitivity to residual stresses and changes in microstructure of ferromagnetic materials, so they are widely used as nondestructive evaluation techniques for inspection of the materials [1–3]. The MBN is produced by the discontinuous changes in magnetization and can be detected by a sensing coil as a stochastic signal.

The detected signal is influenced, among others, by the frequency of the excitation magnetic field [4,5]. In practice, the MBN is measured from frequencies below 0.1 Hz [6–8] up to about 1 kHz [9]. Higher frequencies of the excitation field usually bring several advantages compared to smaller ones, such as a higher magnitude of the MBN [10,11], faster measurement, and smaller number of acquired sample points at the same sampling frequency.

However, increasing the excitation frequency also has some disadvantages especially concerning the excitation field component of the electromotive force (EMF) signal induced in the sensing coil, which rises linearly with the excitation frequency and disturbs the MBN. To suppress this interference component, two encircling sensing coils connected in series opposition can be used [12]. The interference signal is also reduced when we use a pick-up coil with the coil axis placed perpendicular to the

specimen surface. Unfortunately, these techniques does not remove the interference signal completely, so an additional analog and/or digital high-pass filter should be used.

A proper choice of the cut-off frequency of the filter is important to be able to suppress the interference signal and at the same time to preserve the whole useful (MBN) information from the EMF signal, which is not always easy to do and can be a source of error. In this paper we proposed to suppress the interference signal employing the two-stage measurement of the MBN, instead of using a filter. The impact of the method on the most common parameters of the MBN will be studied and the possibility of the usage of the method in measuring the MBN in a wide excitation frequency range will be discussed.

2. Description of the two-stage methods

In the two-stage methods, we subtract two consecutive waveforms of the EMF signal containing the same deterministic interference signal, whose basic frequency is equal to the frequency of the excitation magnetic field. The subtraction can be carried out either in a hardware (hardware two-stage method), or in a software (software two-stage method).

The first step of the hardware two-stage method (Fig. 1) is to acquire an EMF signal during one magnetization cycle, produced by the generator A and started from zero magnetic field strength in a previously demagnetized sample. During this stage the voltage on

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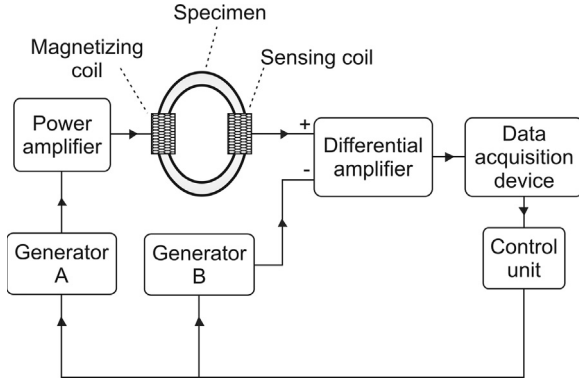


Fig. 1. The principle of the hardware two-stage method.

the output of the generator *B* is set to 0 V and the differential amplifier with a gain of 1 processes only the EMF signal from the sensing coil. The EMF signal is recorded by the data acquisition (DAQ) device and uploaded into the memory of the generator *B*.

In the second stage, the generator *A* starts the same magnetization cycle from zero magnetic field strength as in the previous stage, while the generator *B* synchronously starts to output the waveform uploaded into its memory in the previous stage. The signal at the output of the differential amplifier is therefore the difference between the present and previous EMF signal. In an ideal case, the interference components of both EMF signals cancel each other out, since they should be the same. As a result, the recorded signal is the subtraction of two waveforms of the stochastic MBN signal measured within one magnetization cycle. In a real case, there will be some residual interference component after the subtraction. However, it should be negligible in compare to the MBN provided that certain conditions are fulfilled, especially the generators should have a sufficient precision and we should be able to generate precisely synchronized signals.

In the software two-stage method, we acquire two waveforms of the EMF signal from two consecutive magnetization cycles starting from zero magnetic field strength, and then we subtract them in a computer program. This approach requires only one generator and a single input amplifier. The measurement is then simpler and it is not influenced by the inaccuracy of the second generator. All measurements presented in this paper are conducted by the software two-stage method. One disadvantage of this method is that it requires a DAQ device with a higher resolution in compare to the hardware two-stage method to measure the MBN with the same accuracy, what will be discussed later.

3. Parameters of the resulting MBN

The parameters frequently used to interpret the MBN were calculated from the signals gathered by the classical one-stage method as well as the software two-stage method. The root mean square (RMS) value of the MBN is the most commonly measured parameter of the MBN. The MBN is a zero mean signal and thus its RMS value is equal to its standard deviation. The RMS value was calculated from

$$V_{RMS} = \sqrt{\frac{1}{N} \sum_{i=1}^N V_i^2} \quad (1)$$

where *N* is the number of samples of the MBN signal used for calculating the value of V_{RMS} and V_i is the *i*th sample of the MBN signal.

We can assume that the stochastic components of the subtracted EMF signals are uncorrelated and zero mean processes. According to [13], the standard deviation σ_s of the sum or subtraction of such processes with standard deviations of σ_1 and σ_2 , respectively, can be calculated as follows:

$$\sigma_s = \sqrt{\sigma_1^2 + \sigma_2^2} \quad (2)$$

If we consider that stochastic components of both subtracted EMF signals have the same RMS value and we neglect the remaining deterministic signal after subtraction, the RMS value of the resulting signal after subtraction should be $\sqrt{2}$ times higher than the RMS value of the stochastic component of the EMF signal.

The envelope of the MBN was obtained using the following equation:

$$V_{ek} = \sqrt{\frac{1}{N_e} \sum_{j=kN_e}^{(k+1)N_e-1} V_j^2} \quad (3)$$

where N_e is the number of adjacent samples of the MBN signal used for calculating the *k*th point of the envelope and V_j is the *j*th sample of the MBN signal. Since the envelope was calculated using the similar relation as the RMS value of the MBN, we can expect that also the envelope from the two-stage measurement is $\sqrt{2}$ times higher than that from the classical measurement.

The next parameter obtained from the MBN is the maximum, calculated simply as the maximum of the absolute value of the MBN during the magnetization cycle. The theoretical relationship between the maximum values from the two-stage and classical measurements can be obtained using the assumption that the probability density function $f(v)$ of the stochastic component v of the EMF signal is approximately of Gaussian type with zero mean [14]

$$f(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{-v^2/2\sigma^2} \quad (4)$$

If we subtract two EMF signals with the standard deviations $\sigma_1 = \sigma_2 = \sigma$ of their stochastic components and we use Eq. (2), we will obtain the signal v_s with probability density function

$$f_s(v_s) = \frac{1}{2\sigma\sqrt{\pi}} e^{-(v_s^2/4\sigma^2)} \quad (5)$$

The maximum value of the resulting signal v_s can be calculated by equating the probability density functions of the resulting and subtracted signals

$$\frac{1}{\sigma\sqrt{2\pi}} e^{-v^2/2\sigma^2} = \frac{1}{2\sigma\sqrt{\pi}} e^{-(v_s^2/4\sigma^2)} \quad (6)$$

From this equation we obtain

$$-\frac{v^2}{2\sigma^2} = \ln\left(\frac{1}{\sqrt{2}}\right) - \frac{v_s^2}{4\sigma^2} \quad (7)$$

For high values of v and v_s we can neglect the logarithmic term and then we will get

$$v_s = \sqrt{2}v \quad (8)$$

From this equation we see that the probability density function of the resulting signal is spread by a factor of $\sqrt{2}$, so also the maximum value of the resulting signal after subtraction is $\sqrt{2}$ times higher than the maximum value of the stochastic component of the EMF signal.

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