Journal of ELECTRICAL ENGINEERING, VOL 59. NO 7/s, 2008, 70-73

EFFECT OF NON-IDEAL CONDITIONS ON THE DETERMINATION OF THE BARKHAUSEN NOISE PARAMETERS

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The Barkhausen effect produces a sequence of magnetization avalanches during smoothly changing magnetic fields. The avalanches are the result of the jerky motion of domain walls under presence of pinning forces. The Barkhausen noise avalanches follow a power law distribution for very slow excitations for large samples. Under non ideal conditions, the exponent and cut-off parameters will depend on the conditions of the experiment [1]. In this paper we present results for the effect of excitation frequency and amplitude, sample geometry and the pick-up coil parameters on the Barkhausen noise parameters.

Keywords: Barkhausen noise, steel, statistical analysis, magnetic domain wall

1 INTRODUCTION

Barkhausen noise is widely used for non-destructive testing of magnetic structural materials. In the industrial applications the excitation frequency is in the 1 Hz-100 Hz range, and mainly the RMS values are measured. For the detailed study of noise statistics one usually apply excitation frequencies in the mHz range. When the excitation field changes slowly, it is possible to reveal separated Barkhausen avalanches and analyze their statistical properties and temporal distribution. Strictly we can only use the term "individual avalanches", in the case of the infinitely slow driving rate (adiabatic limit). In measurements, the driving rate is finite and several domain walls in different spatial regions can move.

A Barkhausen avalanche is usually a sum of the motions of many domain walls, so it is important to understand the effect of the different driving rates and geometry parameters on the measured noise signal [2, 3]. Another important difference between the so-called traditional Barkhausen noise measurement and the laboratory arrangement is the geometry. Non destructive industrial measurement often uses surface detectors and samples usually cannot be magnetized throughout because of their size, while the usual laboratory setups use thinned samples with pickup coils wound around them.

In this paper, we examined the noise signal characteristics collected during different driving rates and at different sample sizes and pickup coil parameters. We have also developed an algorithm to simulate the effect of excitation rate and compared its results with the experiments.

2 EXPERIMENTAL DETAILS

The experimental setup consisted of a detector coil connected to a pre-amplifier via a grounded coaxial cable for the noise signal collection, and a solenoid (16400 m^{-1} winding density) connected to a triangular signal generator for the creation of the excitation field. The excitation field was 1.3 mT what was enough to reach saturation (Fig. 3). We have studied structural steel (S235 JRG1), with different sample geometries (the standard size was 50×2×0.15 mm, when the subject was not the geometry effect). The detector coil length was much below and the excitation solenoid length was much above the length of the sample, to assure the homogeneity of the detected noise.

The Barkhausen noise signal – voltage $u(t)$ induced in a search coil – was digitalized by a NI PCI MIO 16E-1 digital acquisition card (sampling frequency 1MHz, 12 bit ADC), and the raw data was saved to disk [4]. A program written in ANSI C was used to post-analyze the measured signal. The statistical analysis of the Barkhausen noise is based on identification of the noise avalanches, and the evaluation of the distribution of their properties or the correlation of these parameters. In the avalanche detection algorithm, a threshold value was

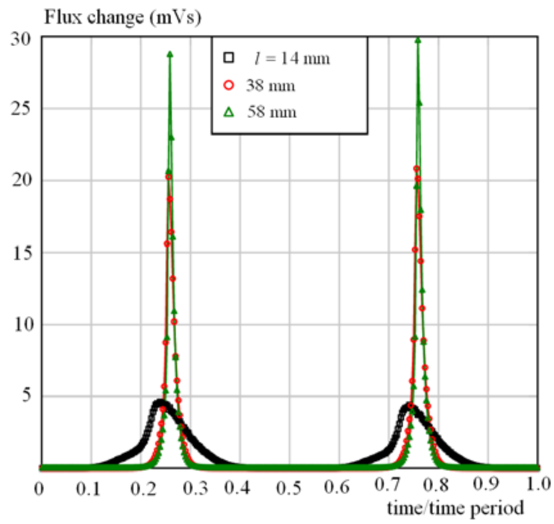

Fig. 1. Temporal change of the avalanche area (Flux change) during a magnetization cycle

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ISSN 1335-3632

utilized in order to reduce the effect of the background noise originating from the environment and the preamplifier circuit. An avalanche starts when the signal rises above the threshold value and ends when the signal returns below that level. The program provides statistical analyses of the avalanches such as the distribution of area, energy, maximum, width, and waiting time between avalanches.

3 GEOMETRY DEPENDENCE

The investigation of the effect of the sample length consisted of shortening an initially 58 mm long sample gradually (48 mm, 38 mm, 28 mm, and 14 mm). Figure 1 shows the temporal change of the avalanche areas (which is proportional to the magnetization) for three lengths. The curves for longer lengths nearly coincide with each other. The graph is made by dividing the time axes up for bins, and summing the avalanches in the bins.

In the case of the shortest sample, the cut-off value of avalanche area distribution was definitely decreased, but the calculated exponents remained nearly the same for all of the lengths.

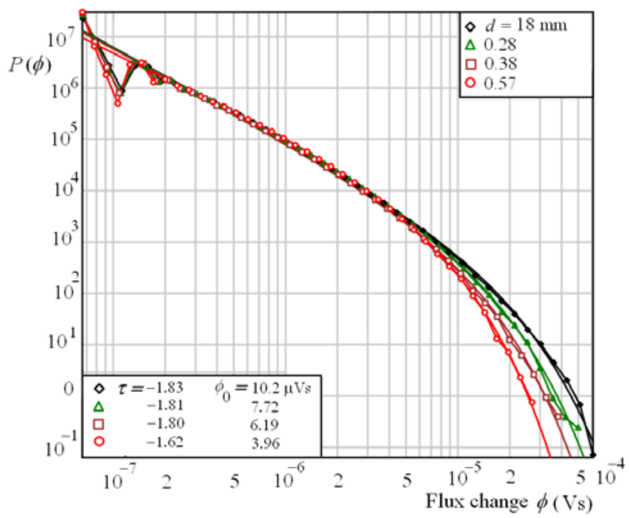

Fig. 2. Avalanche area distributions for different sample thicknesses

For the determination of the effect of sample thickness we have electro-chemically etched a sample. Figure 2 shows the above mentioned avalanche area probability distribution $P(\phi)$ for different sample thicknesses. The graph is made by logarithmic binning what is the common technique in the case of power-law functions. We used the Levenberg-Marquardt algorithm to fit these functions: $P(\phi) = a\phi^{-\tau}e^{-\phi/\phi_0}$, where τ is the exponent of the power-law distribution, and ϕ_0 is the scaling factor of the exponential cut-off.

There is no remarkable change in the value of the exponents, but the cut-off values decrease with increasing sample thickness.

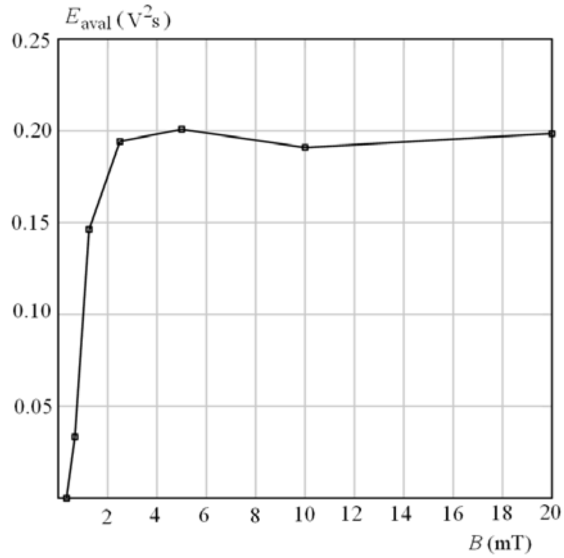

Fig. 3. Avalanche signal energy as a function of the excitation amplitude

We have studied the effect of different pickup coil parameters as well. One of the most important parameters during measurement is the arrangement and geometry of the pickup coil. We have compared electric signal measured using pickup coils with different number of turns. Again, there was only a small change in the exponents of the avalanche property distributions, and an increase of the cut-off values with increasing number of turns. This increase is linear with the number of turns agreeing with the simple induction equation for solenoids. In general the effect of the change of the pickup coil parameters (length, area of cross section) could be accounted for the changed inductive coupling to the sample.

4 EXCITATION PARAMETER DEPENDENCE

We have studied the effect of the excitation amplitude and frequency on the parameters of noise signal. The effect of excitation field amplitudes was under the condition that the excitation rate was kept constant. We have found no systematic change in the avalanche property distribution exponents. On the other hand, the summed avalanche area (the total flux change) and the “signal energy” during a whole magnetization cycle, defined as

$$E_{aval} = \int_{-\infty}^{\infty} u^2(t)dt = \int_{-\infty}^{\infty} \mathcal{U}(\omega)\mathcal{U}^*(\omega)d\omega\,,$$

showed saturation for higher amplitudes when the sample was fully magnetized (Figure 3). Above $u(t)$ is the voltage induced in a search coil and $\mathcal{U}(\omega)$ is its Fourier spectrum.

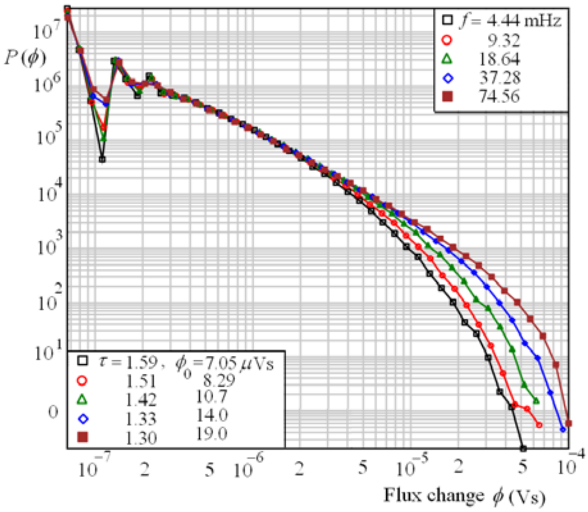

Fig. 4. Avalanche area distributions for different driving rates - experiment

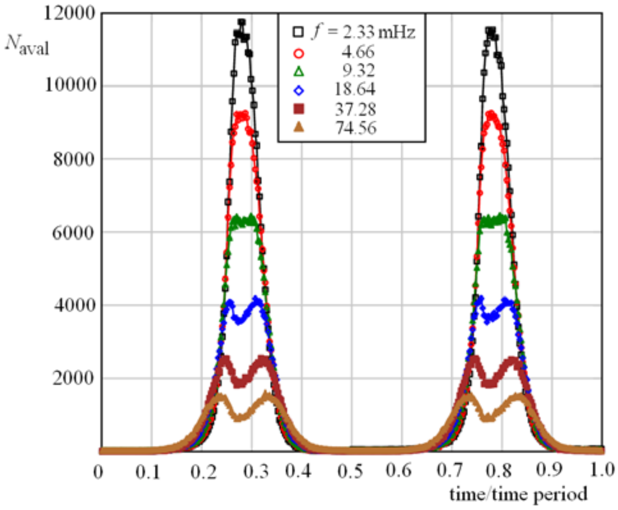

Fig. 5. Temporal change of the number of Barkhausen avalanches during a magnetization cycle - experiment

We have studied the frequency dependence as follows. The excitation amplitude was set to a value what can saturate the sample. By changing the slope of the excitation field the frequency (f) could be varied between 2 mHz and 75 mHz.

We have found that, the total area was decreasing with increasing frequency, while the total energy was increasing.

Figure 4 shows the avalanche area distributions for different driving rates. The exponents are decreasing with increasing driving rate.

Figure 5 shows the temporal change of the number of Barkhausen avalanches (N_{aval}) for different driving rates.

There is a decrease in the number of avalanches with increasing driving rate, and the original single maxima splits to two parts. On the other hand the temporal change of the avalanche area and the signal energy remains single peaked. The sum of the area is decreasing and the signal energy is increasing with increasing driving rate.

5 EXTRAPOLATION OF FREQUENCY DEPENDENCE

We have simulated the effect of the driving rate on the signal parameters. An algorithm was developed to extrapolate signal from the signal measured at the lowest driving rate. The algorithm is simulating a "linear superposition" [5] of avalanches due to an increasing random overlap of different independent transition processes with the increasing driving rate.

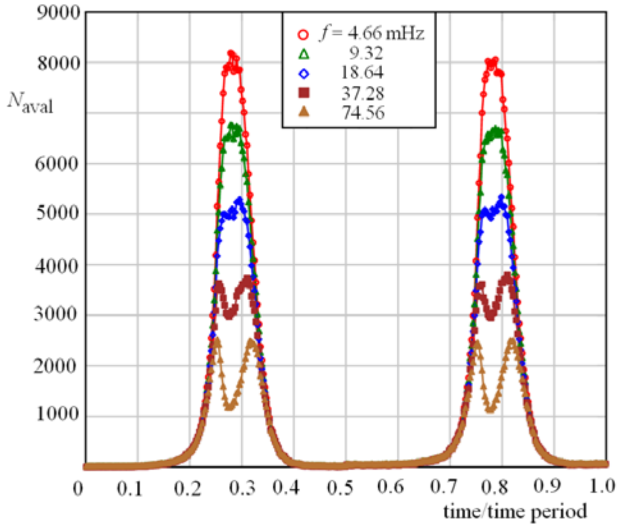

Fig. 6. Temporal change of the number of Barkhausen avalanches during a magnetization cycle – extrapolated signals

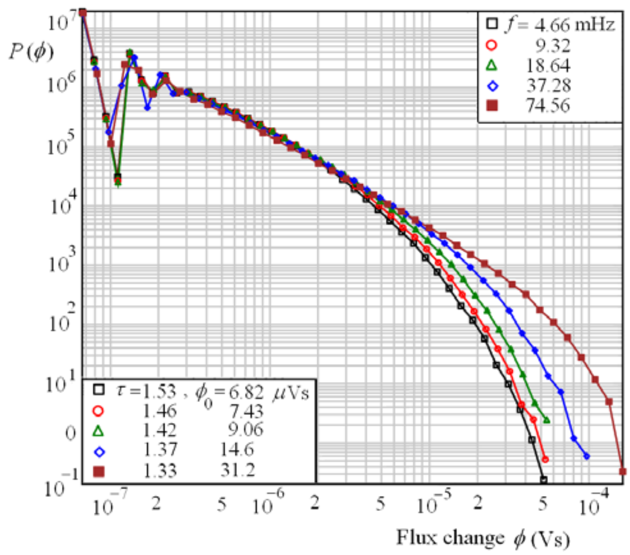

Fig. 7. Avalanche area distributions for different driving rates – extrapolated signals.

In the first approximation, if we increase the driving rate, the distance between avalanches decreases and merging of the avalanches can occur. For example, if we increase this rate by a factor 2, the simulation moves the

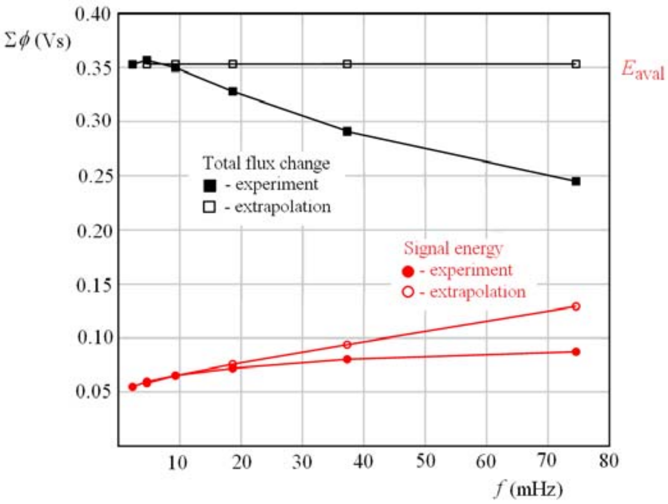

Fig. 8. Summed up avalanche area (total flux change $\Sigma\phi$) and signal energy (E_{aval}) as functions of the excitation frequencies (f) for experimental and simulated noise signals

avalanches 2 times closer to the starting point in time, so some of them will merge into a bigger avalanche (in this case the time duration of the whole signal will be half of the original). Figure 6 shows the number of avalanches during one magnetization cycle, which shows remarkable agreement with the experimental results in Figure 5. Figure 7 shows the avalanche area distribution in the case of extrapolated signals. There is again a good agreement with the experimental results (Fig. 4). Figure 8 shows the total avalanche area (total flux change $\Sigma\phi$) and the signal energy (E_{aval}) for the measured and extrapolated signals. The extrapolated area is constant because the algorithm preserves the sum of the area of the avalanches. The total measured area is decreasing with the driving rate. The extrapolated total energy increases faster then the measured values. We attribute these differences to the growing contribution of the effect of eddy-current at higher driving rates.

6 SUMMARY

We have studied the effect of sample geometry and the excitation parameters on the statistical properties of the Barkhausen avalanches. The sample geometry affected the cut-off value of the power law distribution and the time dependence of the noise response, but had little effect on the exponents. The amplitude of the excitation affected mainly the summed avalanche area and signal energy, leading to a saturating curve for higher excitation amplitudes.

The excitation frequency had a strong effect on all noise parameters. We have developed a method to simulate higher frequency noise signals from the signal measured at the lowest frequency based on the overlap of noise signals. With this simple model the observed trends in the exponent and cut-off values and in the number of separate avalanches could be explained.

Acknowledgement

The financial support of the NKFP3A/043/2004 grant and the KPI-Genomnanotech-DEBRET 06/2004 project are gratefully acknowledged.

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Received 28 June 2008