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Comprehensive analysis of Barkhausen emission spectra using pulse height analysis, frequency spectrum, and pulse wave form analysis

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Abstract

The dependence of magnetic Barkhausen emissions (MBE) upon both field excitation and detection frequencies and excitation wave form was studied in order to investigate two of several crucial factors which affect the emissions. Sinusoidal, triangular, and square wave forms were used to generate the MBE and the pulse height spectra, frequency spectra, and pulse wave forms of these signals were analyzed. The frequency spectra of sinusoidal and triangular alternating field excitations showed similar behavior but the spectrum under square wave excitation was different due to the existence of high frequency components during square wave switching. As yet, no common standard has been agreed upon for parameterization and representation of Barkhausen signals. It appears from this work that field excitation wave form and frequency should define the inputs, while detection frequency range, pulse height spectrum, frequency spectrum, and emitted pulse wave form analysis should be used to quantify the output.

Keywords

Ames Laboratory, CNDE, Electrical and Computer Engineering, Frequency analyzers, Spectrum analysis, Emission spectra, Barkhausen effects, Molecular beam epitaxy

Disciplines

Electromagnetics and Photonics | Engineering Physics | Materials Science and Engineering

Comments

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Comprehensive analysis of Barkhausen emission spectra using pulse height analysis, frequency spectrum, and pulse wave form analysis

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I. INTRODUCTION

The magnetization processes in a ferromagnetic material can be investigated in two ways; either by the averaged macroscopic dependence of magnetization as represented in the magnetic hysteresis loop[1,2] or by the microscopic changes in magnetization represented by the Barkhausen effect.[3–9] Most previous studies on the Barkhausen effect reported the use of quasi-dc magnetization, which can simply be considered as a very slow change in the magnetic field of the sample. Our recent studies have shown that an ac technique to generate the Barkhausen emissions in magnetic material gives much cleaner and more reproducible Barkhausen signals.[10–12]

There are several variables in Barkhausen effect which determine the characteristics of steplike discontinuities in magnetization as the magnetic field is changed. Thus any direct comparisons between results reported by different groups should be made carefully. The use of sinusoidal and triangular wave form at 1–5 mHz have been reported previously.[3–9]

II. EXPERIMENTAL PROCEDURE

In this work, an annealed polycrystalline nickel specimen was used. Its magnetic properties and Barkhausen count rate measurements obtained under quasi-dc conditions have been reported elsewhere.[13] Measurement techniques used in the present investigation include the voltage wave form, the pulse height spectrum, and fast Fourier transform (FFT) frequency spectrum of magnetic Barkhausen emissions (MBE). The experimental system was described previously.[10,12] In order to reduce the number of factors influencing the MBE spectrum, the number of turns and shape of the detecting coil which was wound on the specimen were chosen carefully as 50 turns in one layer at the center of the specimen.

III. RESULTS AND DISCUSSION

The form of external field excitation (e.g., sinusoidal, square, or triangular wave form) has a critical effect on the Barkhausen emissions. Figure 1 shows the wave forms of the MBE when different field excitation wave forms were used. The MBE wave forms were obtained using an ac field amplitude of 8 kA/m at 30 Hz with dc offset. The MBE in the cylindrical ferromagnetic specimen, in a field applied in a direction parallel to the cylinder axis, resulted from a small change in the applied field. These MBE events were considered as a change in magnetization, resolved in a direction parallel to the applied field, over a small volume. It was observed that changes in the field wave form lead to different emission pulse shapes, however, it was also observed in all cases that the voltage profiles underwent an exact mirror reflection in the $V=0$ axis when the direction of the change of magnetic field was reversed. This indicates that the same microscopic mechanisms occurred when the field was increasing and decreasing.

The maximum voltage amplitude of Barkhausen pulse wave form observed was 1.2 V. This was obtained with the use of a square wave excitation of 30 Hz and field amplitude 8 kA/m. Sinusoidal and triangular wave forms were also employed in separate measurements and these resulted in amplitudes of 0.5 and 0.3 V, respectively. The signal-to-noise ratio was typically 80:1, 33:1, and 20:1 in these cases, respectively. The noise spectrum is shown in Fig. 1(d).

These trends were also obtained in the pulse height spectra. The use of square wave excitation field can lead to

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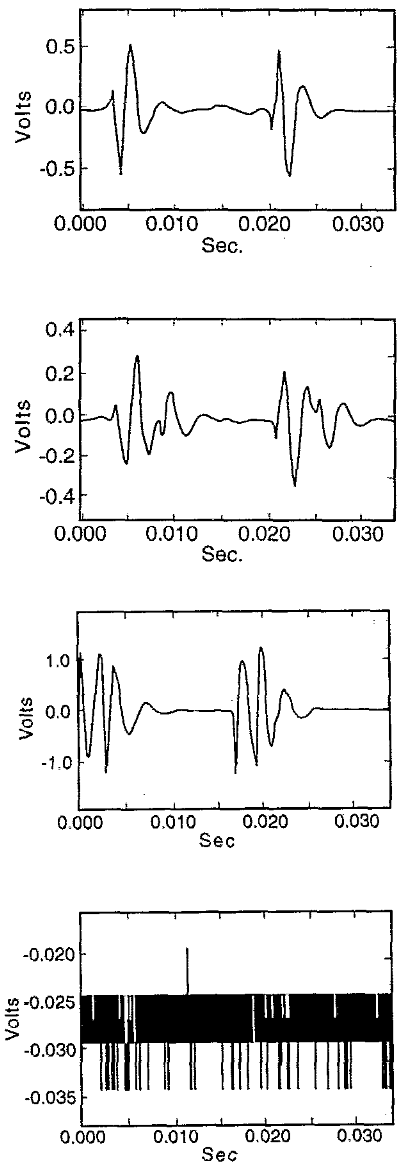

FIG. 1. Barkhausen wave forms as a function of time under ac field amplitude of 8 kA/m at 30 Hz with dc offset of (a) sinusoidal, (b) triangular, (c) square excitations, and (d) system noise.

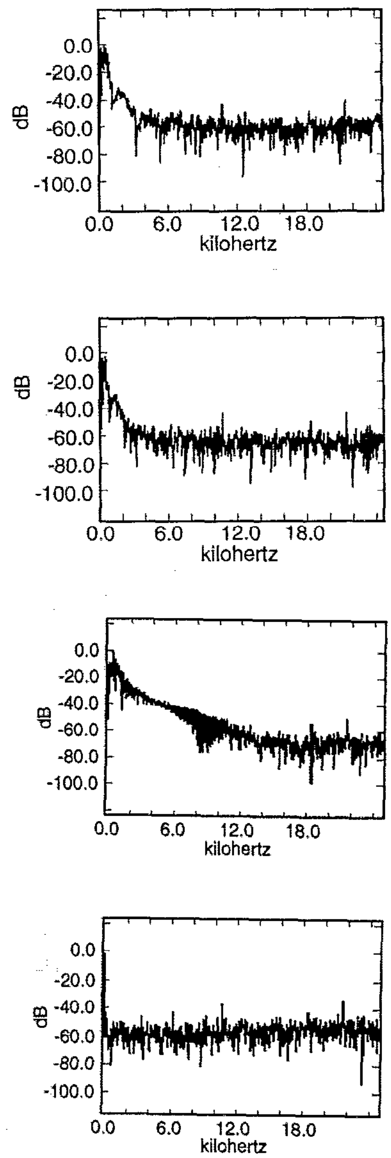

FIG. 2. The corresponding FFTs of the wave forms shown in the Fig. 1 in the same letter order.

spurious signals. However, the sinusoidal or triangular wave forms were in general less susceptible to this problem and were therefore more suitable for generation of the MBE in the materials.

The frequency spectra of the MBE wave forms are shown in Fig. 2. These FFTs indicated that the use of different excitation field wave forms would give distinct spectra in each case. Among these spectra those generated by sinusoidal and triangular wave forms were quite similar while that generated by square wave form was clearly different. As was reported,[14] according to Campbell's theorem which was valid for the MBE, the power density spectrum which is another form FFT showed that the Barkhausen signals decreased by at least 20 dB per decade of frequency. The MBE within the 100 kHz range would be minimum 60 dB below the low frequency components. Since the high frequency components of the MBE were mixed with the system noise it is difficult to distinguish them under normal circumstances at higher frequencies.

The MBE signals occur within the range of excitation frequency up to few hundred kilohertz, and therefore the choice of detecting or analyzing frequency was important. Thus the band pass filter was set at 300 Hz–300 kHz. When wide band measurements were conducted the change in the system noise had a crucial effect on the detected high frequency signals. The MBE, which were generated by using alternating magnetic field in different wave forms, were dependent on the frequency of the magnetic excitation field due to skin depth, since the penetration of the field is inversely proportional to the square root of excitation field frequency. In the present results, 30 Hz was found to be optimal for obtaining clearly defined Barkhausen signals. An increase in frequency of excitation

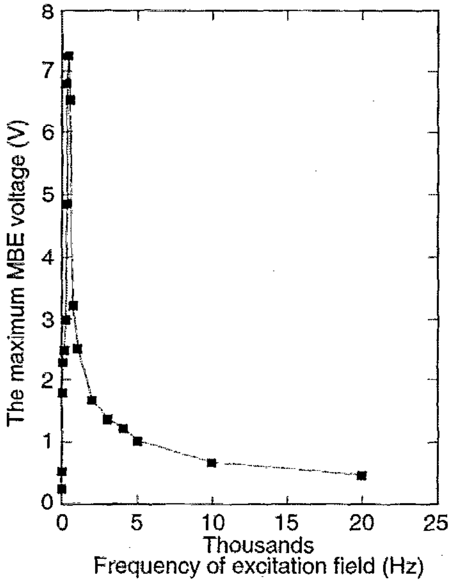

FIG. 3. The maximum MBE voltage as a function of frequency of excitation field, 8 kA/m in sinusoidal wave form at 30 Hz with dc offset.

field resulted in higher MBE activities and amplitudes until one reached a critical excitation frequency, in our case it was between 300 and 400 Hz depending on the wave form. Figure 3 shows the frequency of excitation field vs the maximum MBE voltage that was determined from their MBE signals. This trend was regardless of the wave form of the excitation field. The MBE voltage increases up to 300 to 400 Hz, shows a maximum, and then decreases. The only difference in this respect from one wave form to another was that the maximum voltage value at the peak was not the same.

IV. CONCLUSIONS

This work demonstrated conclusively that the microscopic changes in magnetization known as the Barkhausen effect can be distinguished on the basis of frequency content. The use of an ac excitation field with a wave form of sine and triangle is suggested at present, although it may eventually be best to sweep the field H with time in order to ensure that on the bulk scale dB/dt=constant. The problems of the square wave form arise from the high frequency content at the voltage step. Variations due to the use of different wave forms appeared clearly through all the FFT measurements. The dependence of the maximum MBE voltage in the Barkhausen emission pulse wave form on the field excitation frequency was similar in form for all three field excitation wave forms. However the absolute value of MBE voltage was dependent on the field excitation wave form.

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