IRis

Northeastern University

Electrical and Computer Engineering Faculty Publications

Department of Electrical and Computer Engineering

April 15, 1997

Modeling of Barkhausen noise in magnetic core material: application of Preisach model

H. How

L. Sun

C. Vittoria
Northeastern University

Recommended Citation

How, H.; Sun, L.; and Vittoria, C., "Modeling of Barkhausen noise in magnetic core material: application of Preisach model" (1997). *Electrical and Computer Engineering Faculty Publications.* Paper 93. http://hdl.handle.net/2047/d20002264

This work is available open access, hosted by Northeastern University.

AIP Journal of Applied Physics

Modeling of Barkhausen noise in magnetic core material: Application of Preisach model

H. How, L. Sun, and C. Vittoria

Citation: J. Appl. Phys. **81**, 5594 (1997); doi: 10.1063/1.364610
View online: http://dx.doi.org/10.1063/1.364610
View Table of Contents: http://jap.aip.org/resource/1/JAPIAU/v81/i8
Published by the American Institute of Physics.

Related Articles

Temperature dependence of microwave voltage emission associated to spin-transfer induced vortex oscillation in magnetic tunnel junction
Appl. Phys. Lett. 100, 042408 (2012)

0.7BiFeO3-0.3BaTiO3-Y3Fe5O12 composites with simultaneously improved electrical and magnetic properties
J. Appl. Phys. 111, 024104 (2012)

Weak ferromagnetic ordering in Ca doped polycrystalline BiFeO3
J. Appl. Phys. 111, 023910 (2012)

Comment on “The electromagnetic property of chemically reduced graphene oxide and its application as microwave absorbing material” [Appl. Phys. Lett. 98, 072906 (2011)]
Appl. Phys. Lett. 100, 046101 (2012)

Large anisotropic remnant magnetization tunability in (011)-La2/3Sr1/3MnO3/0.7Pb(Mg2/3Nb1/3)O3-0.3PbTiO3 multiferroic epitaxial heterostructures
Appl. Phys. Lett. 100, 043506 (2012)

Additional information on J. Appl. Phys.

Journal Homepage: http://jap.aip.org/
Journal Information: http://jap.aip.org/about/about_the_journal
Top downloads: http://jap.aip.org/features/most_downloaded
Information for Authors: http://jap.aip.org/authors

ADVERTISEMENT

Downloaded 30 Jan 2012 to 129.10.105.52. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions

Modeling of Barkhausen noise in magnetic core material: Application of Preisach model

H. How
ElectroMagnetic Applications, Inc., Boston, Massachusetts 02109

L. Sun and C. Vittoria
Northeastern University, Boston, Massachusetts 02115

The Preisach model is utilized to model Barkhausen noise in magnetic core materials. Barkhausen noise is generated each time the magnetization goes through a sudden change at a local site in the core material. In this article we examine the relationship between the shape of magnetization hysteresis loops to details of Barkhausen noise levels or excitations. On the basis of hysteresis loops alone it may be possible to profile the noise spectrum of a magnetic core. © *1997 American Institute of Physics.* [S0021-8979(97)39308-6]

I. INTRODUCTION

The random motion of domain walls in magnetic cores will generate Barkhausen noise which will ultimately limit the sensitivity of a fluxgate magnetometer. Presently, there is no theoretical guidance in choosing magnetic materials which minimizes Barkhausen noise. There is a need to formulate Barkhausen noise in terms of magnetic parameters which are conventionally measured, such as hysteresis loops and (first order) magnetization curves. In this article we propose the use of the Preisach model[1] to establish the theoretical basis on Barkhausen discontinuities. The Preisach model assumes a distribution function $\mu(h_\alpha,h_\beta)$ in a hypothetical plane (h_α,h_β) where the two axes h_α and h_β denote the magnetic coercive forces required to switch a local magnetization reversal center. In the Preisach model one assumes that the magnetic response of the core material can be described collectively by many local reversal centers, or magnetic domains, whose distribution is $\mu(h_\alpha,h_\beta)$. A local reversal center is specified by two coercive forces, h_α, and h_β, and upon magnetic reversal the magnetization of the center is switched from $-4\pi M_s$ to $+4\pi M_s$, or vice versa. Here, $4\pi M_s$ denotes the saturation magnetization of the core material, which may be conveniently normalized to a unit magnitude. The important feature of the Preisach model is that the model possesses nonlocal memory such that the magnetization history, or hysteresis, is memorized in terms of a set of input driving-field maxima.[1]

A Barkhausen jump is generated if the magnetization value is reversed in a local domain center. The total amount of Barkhausen jumps will be dependent on the volume of the magnetic core and the density of domains, which is a function of the following parameters: geometry, anisotropy, magnetostriction, exchange stiffness, and conductivity, for example. In this article we consider only the normalized behavior relating Barkhausen jumps with magnetization curves, assuming the other parameters will not change among core materials. This provides a direct comparison between core materials, emphasizing their magnetization properties. However, realistic calculations on ribbon-shaped magnetic cores (taking into account domain configuration and switching velocity of domain walls) have also been performed; they will be published elsewhere.[2]

II. DISTRIBUTION FUNCTION

Instead of using experimentally measured Preisach distribution functions, $\mu(h_\alpha,h_\beta)$, we proceed here with hypothetical ones which give rise to magnetic hysteresis loops with prescribed shapes, including squareness, slantness, and corner roundness. We develop this hypothetical distribution function as follows. Consider first an ideal hysteresis loop of rectangular shape with coercive force h_0. The corresponding distribution function can then be trivially conjectured, consisting of a delta function given as

$$\mu(h_\alpha,h_\beta)\propto\delta(h_\alpha+h_0)\,\delta(h_\beta-h_0). \tag{1}$$

Next, we consider the distribution function to be flattened to contain a uniform distribution in a rectangular area specified by $-h_2\leqslant h_\alpha\leqslant -h_1, h_1\leqslant h_\beta\leqslant h_2$. In this case the distribution function becomes

$$\mu(h_\alpha,h_\beta)\propto[S(h_\alpha-h_1)-S(h_\alpha-h_2)][S(h_\beta+h_2)-S(h_\beta+h_1)]/4, \tag{2}$$

where $S(x)$ is the step function given as

$$S(x)=1,\quad \text{if } x>0,$$
$$=0,\quad \text{if } x<0. \tag{3}$$

The proportional constants in Eqs. (1) and (2), as well as in Eqs. (8) and (9) below, can be determined from the normalization condition

$$\int dh_\alpha dh_\beta \mu(h_\alpha,h_\beta)=1. \tag{4}$$

In Eq. (4) integration is performed in a triangular area defined by the following three half-planes:[1,2]

$$h_\alpha\leqslant h_\beta,\quad h_\alpha\geqslant -1,\quad \text{and } h_\beta\leqslant 1. \tag{5}$$

The above conditions assume that the maximum possible coercive force associated with local reversal centers is ± 1, which result in normalized hysteresis loops requiring a magnetizing field of strength ± 1 to reach saturation.

Using the construction rules described in Ref. 1 the hysteresis loop corresponding to Eq. (2) can be readily obtained, containing piecewise linear (limiting) magnetization curves in the shape of a parallelogram.[2] The squareness of the par-

 0021-8979/97/81(8)/5594/3/$10.00 © 1997 American Institute of Physics

Downloaded 30 Jan 2012 to 129.10.105.52. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions

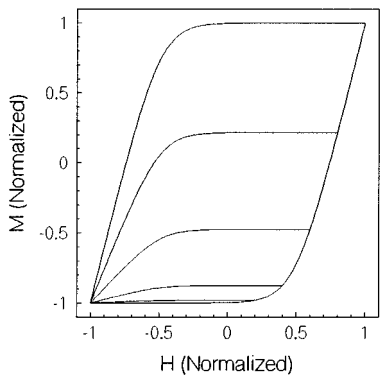

FIG. 1. Hysterisis loop and magnetization curves generated by the distribution function of Eq. (8).

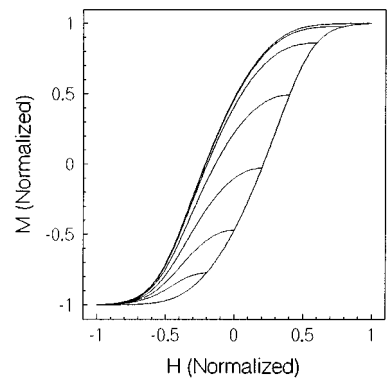

FIG. 2. Hysterisis loop and magnetization curves generated by the distribution function of Eq. (9).

allelogram, or the slope of the sides of the parallelogram, is inversely proportional to $h_2 - h_1$. Therefore, one concludes that the squareness of a hysteresis loop is manifested as the effective area that the distribution function assumes in the (h_α, h_β) plane possessing appreciable amplitude; the more local centers distribute in the two sides of the diagonal line, $h_\alpha = -h_\beta$, the hysteresis loop will depart more from a rectangular shape. As a reminder, the distribution function must satisfy the following congruent condition:[1]

$$\mu(h_\alpha, h_\beta) = \mu(-h_\beta, -h_\alpha). \tag{6}$$

The sharp corners appearing in a parallelogram-shaped hysteresis loop can be smoothed by assuming a smooth transition function. This can be done by replacing the step-functions in Eq. (3) with hyperbola-tangent functions possessing different slopes in transition:

$$S(x;\gamma) = (1 + \tanh\ \gamma x)/2. \tag{7}$$

We note that a step function, Eq. (3), is approached if the transition rate γ is taken to be infinite. In the following calculations we assume $\gamma = 10$ as a convenient choice for hysteresis loops. As an example, we plot in Fig. 1 the hysteresis loop and first-order magnetization curves corresponding to the following distribution function:

$$\mu(h_\alpha, h_\beta) \propto [1 + \tanh\ \gamma(h_\alpha - 0.5)][1 - \tanh\ \gamma(h_\beta + 0.5)]/4. \tag{8}$$

Before we proceed any further, we wish to point out a very important feature of the classical Preisach model which has not been mentioned in the literature. This is associated with the non-negativeness of the distribution function. For the Preisach model to be realistic, it is imperative to assume that the distribution function be non-negative throughout the domain of its arguments. When this condition is satisfied, one can prove in a straightforward manner that the slope of a resultant first-order descending (ascending) magnetization curve is always nonincreasing (nondecreasing), as seen in Fig. 1. The reverse of this statement is also true, as it can readily be verified by using Eq. (5) of Ref. 1. This property provides us with a convenient check on the measured first order magnetization curves of a core material.

Let us now examine a distribution function with which the reversal centers are distributed with population near the origin of the hypothetical plane (h_α, h_β):

$$\mu(h_\alpha, h_\beta) \propto [1 - \tanh\ \gamma(h_\alpha - 0.5)][1 + \tanh\ \gamma(h_\beta + 0.5)]/4. \tag{9}$$

The resultant hysteresis loop and first-order magnetization curves are plotted in Fig. 2. When comparing Fig. 2 with Fig. 1, we conclude that a slanted hysteresis loop is associated with a distribution function whose majority centers impose smaller cercive forces than that required to reach saturation. The hysteresis loop of Fig. 1 corresponds to hard cores, whereas that of Fig. 2 is for soft cores.

In Ref. 2 we have discussed a variety of Preisach distribution functions. One possible distribution is that a large population of local reversal centers require large unbalanced bias field, $h_\alpha - h_\beta$. This results in enlarged tip angles at the hysteresis loop ends and the curvature of the (first order) magnetization curves may even change sign: they become convex upward away from the limiting curves, the hysteresis loop. Hysteresis loop and magnetization curves of this kind are not commonly seen among practical core materials.

III. BARKHAUSEN NOISE

We assume that the magnetization process takes place from the -1, or $-M_a$, state of the magnetic core to the $+1$, or $+M_s$, state. A local center will switch its magnetization values from -1 to $+1$ when the bias field is increasing with a magnitude larger than h_α, the ascending case, or from $+1$ to -1 when the bias field is decreasing with a magnitude smaller the h_β, the descending case. This switch takes place in finite time, normally through the sweep of magnetic domain walls. In the linear regime for which the stability criterion for domain wall motion is not violated, a domain wall, once nucleated and released from a trapping center, travels with a finite velocity which is proportional to the local driving field, or $h_\alpha - h_\beta$.[2] We note that h_α may not equal $-h_\beta$, since the trapping center can provide some kind of local effective field in a preferred direction, resulting in unbalanced bias in a local reversal center assumed by the Preisach model.

Downloaded 30 Jan 2012 to 129.10.105.52. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions

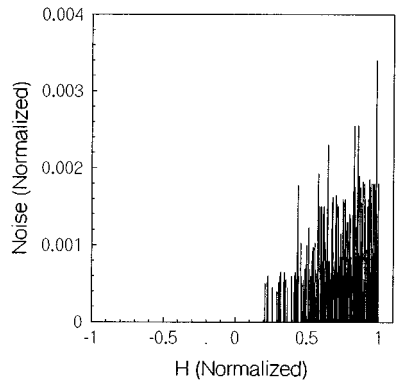

FIG. 3. Barkhausen noises associated with the distribution function of Eq. (8).

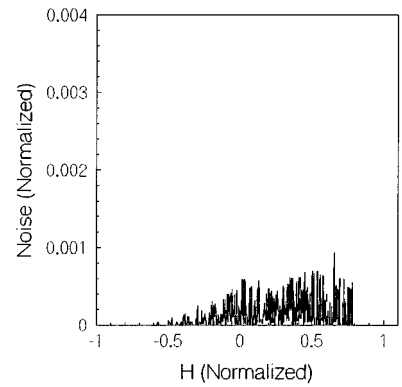

FIG. 4. Barkhausen noises associated with the distribution function of Eq. (9).

We further assume that, before annihilation with another domain wall of opposite polarity or with the core surfaces, the distance traveled by each of the domain walls is approximately the same. Or, equivalently, we assume the domains presented in the unmagnetized state of the core are approximately of the same size. This assumption is true for a homogeneous core possessing uniform composition. As such, the switch time of a domain wall in a reversal center is proportional to $1/(h_\alpha - h_\beta)$, and the generated Barkhausen noise is of an amplitude proportional to $(h_\alpha - h_\beta)$, since the noise is picked up by a Helmholtz coil via the Faraday law. The noise spike is of a width proportional to $1/(h_\alpha - h_\beta)$, since we have assumed each center will switch an approximately equal amount of total flux upon reversal.

The stochastic motion of Barkhausen jumps can now be theoretically simulated. We assume there are totally N local reversal centers participating in the Preisach model, and the magnetization process takes P successive steps to finish, magnetizing the core from $M=-1$ to $M=+1$. At every instant of time the active centers are defined as those whose coercive force, h_α, is kept up by the magnetization field. The active centers will switch their magnetization value from -1 to $+1$ in a time interval Δt corresponding to each succession of the magnetization step. The time instant at which an active center switches its magnetization value is unknown. However, we may assume that reversal action can take place equally likely during the whole length of Δt. As such, we define for each reversal center a random number uniformly deviating in the interval between t and $t+\Delta t$, denoting the time at which magnetization reversal occurs at that center. In the following simulation calculations, we assume $N=1000$ and $P=21$.

Figures 3 and 4 show the calculated Barkhausen noises corresponding to magnetization of core materials whose distribution functions are specified by Eqs. (8) and (9), respectively. For these simulations the induced Barkhausen noise is more intense in Fig. 3 than Fig. 4, indicating that the more the hysteresis loop resembles a square (a hard core), the more intense the noise will appear. The other difference between Figs. 3 and 4 is that for the squared loop (Fig. 3), the noises are concentrated more near the end of the magnetization process.

Finally, we wish to mention that before reaching magnetic saturation Barkhausen noise is very difficult to measure in a soft core. This is because the permeability value of a conventional unsaturated magnetic-soft core is usually so large that the generated Barkhausen signals are almost totally concealed in the core region not to be readily picked up by a secondary coil. Barkhausen noise can be measured in the saturated state of a core material.[3] However, in order to model the noise spectrum in a saturated core one would instead use the modified Preisach model,[4] since it contains a fully reversible component in the added hysteresis nonlinearity; the classical Preisach model is simply inadequate in addressing any of these reversible magnetization processes.

[1] I. D. Mayergoyz, Phys. Rev. Lett. **56**, 1518 (1986).
[2] H. How, T.-M. Fang, and C. Vittoria (to be published).
[3] D. C. Scouten, IEEE Trans. Microwave Magn. **Mag-6**, 383 (1970).
[4] I. D. Mayergoyz and G. Friedman, IEEE Trans. Microwave Magn. **Mag-24**, 212 (1988).

Downloaded 30 Jan 2012 to 129.10.105.52. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions