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ON THE SHAPE OF THE POWER SPECTRUM OF THE BARKHAUSEN NOISE*

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An expression is derived for the power spectrum of the Barkhausen pulses of different shape. It is shown that the power spectrum is significantly influenced by the shape of the elementary Barkausen pulses.

ФОРМА ЭНЕРГЕТИЧЕСКОГО СПЕКТРА ШУМА ВЫЗВАННОГО ЭФФЕКТОМ БАРКГАУЗЕНА

В работе выведено выражение для энергетического спектра шума, вызванного баркгаузеновскими импульсами различной формы. Показано, что энергетический спектр существенно зависит от формы элементарных баркгаузеновских импульсов.

INTRODUCTION

It is known that the magnetization process of a ferromagnetic material is associated, within a large part of the hysteresis loop, with jumps of the Bloch walls which give rise to the Barkhausen noise. The power spectrum of the Barkhausen noise has been calculated be several authors as P. Mazzetti [1], G. Montalenti [2] and Celasco et al. [3]. However, almost all previous studies presupposed that all Barkhausen pulses are equal and have a simple exponential shape. The purpose of the present work is therefore the study of the influence of the shapes of Barkhausen pulses on the power spectrum.

II. THE CALCULATION OF THE POWER SPECTRUM CONDUCTING SAMPLES

The power spectrum of the statistically independent Barkhausen pulses can be written in the form

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$$\Phi(\omega)=2a_0^2 n|F(\omega)|^2 \tag{1}$$

where a_0 is the mean value of the amplitude of elementary pulses, n is the average number of pulses per unit time and $F(\omega)$ is the Fourier transform of the elementary pulse. In the preceding paper [4] we have derived an expression for the time dependence of the Barkhausen pulse

$$\varepsilon(t)=C(M,\gamma)\,t^{-2}\exp(-m/4\gamma^2 t), \tag{2}$$

where $C(M,\gamma)=\mu M/2\gamma\sqrt{\pi}$, $\gamma^2=1/\mu\sigma$, M is the magnitude of the magnetic dipole which describes the Barkhausen jump, μ is the reversible permeability, σ the electrical conductivity of the sample and m is the distance of the origin of the jump from the surface of the sample; we can therefore write

$$\Phi(\omega)=2na_0^2\left|C(M,\gamma)(2\pi)^{-1}\int_0^\infty t^{-2}\exp(-\alpha/t-\mathrm{i}\omega t)\,\mathrm{d}t\right|^2, \tag{3}$$

where $\alpha=m/4\gamma^2$. The integral in (3) may be evaluated if we use the substitution $t=1/\tau$. Then

$$\int_0^\infty t^{-2}\exp(-\alpha/t-\mathrm{i}\omega t)\,\mathrm{d}t=\int_0^\infty \exp(-\alpha\tau-\mathrm{i}\omega/\tau)\,\mathrm{d}\tau=$$

$$=\sqrt{4\mathrm{i}\alpha\omega}/\alpha K_1(\sqrt{4\mathrm{i}\alpha\omega}), \tag{4}$$

where K_1 is a Mac Donald function of order one. Now we substitute (4) into (3). Then we obtain

$$\Phi(\omega)=nC^2(M,\alpha)/2|\sqrt{4\mathrm{i}\alpha\omega}\,K_1(\sqrt{4\mathrm{i}\alpha\omega})|^2. \tag{5}$$

We shall now study the behaviour of the function (5). We use the identity

$$K_1(z)=-\pi/2(J_1(\mathrm{i}z)+\mathrm{i}N_1(\mathrm{i}z)), \tag{6}$$

where J_1, N_1 are a Bessel and a Neuman function, respectively. If $\omega\to 0$, then $J_1(\mathrm{i}z)\to 0$ and $N_1(\mathrm{i}z)\cong 2/\mathrm{i}\pi z$. Thus

$$\Phi(\omega)_{\omega\to 0}=nC^2(M,\alpha)/\pi\alpha. \tag{7}$$

For high frequencies we use an approximative expression for the Mac Donald function

$$K_1(z)\cong\sqrt{\pi/2z}\,\mathrm{e}^{-z}. \tag{8}$$

When (8) is substituted into (5) we obtain

$$\Phi(\omega)=\pi n_0 C^2(M,\alpha)\sqrt{\alpha\omega}\,\mathrm{e}^{-\sqrt{8\alpha\omega}}. \tag{9}$$

III. THE POWER SPECTRUM IN THE CASE OF NON-CONDUCTING SAMPLES

Roditchev and Ignatchenko [5] derived, using some simplifying assumption, the following expression for the velocity of the domain wall during the Barkhausen jump

$$v(t)=ap(n_0^2/p^2-1)\,\mathrm{e}^{-n_0 t}\sinh pt, \tag{10}$$

where a, p, n_0 are material constants. Because of the lack of the eddy current in the non-conducting samples the shape of the elementary Barkhausen pulse is given also by the equation (10). Then

$$F(\omega)=ap(n_0^2p^{-2}-1)\int_0^\infty \mathrm{e}^{-(n_0+\mathrm{i}\omega)t}\sinh pt\,\mathrm{d}t. \tag{11}$$

Since $p=\sqrt{n_0^2-k^2}$ and $n_0>k$, we have

$$F(\omega)=a(n_0^2p^{-2}-1)/4B\left(\frac{n_0+\mathrm{i}\omega}{2p}-\frac{1}{2},2\right). \tag{12}$$

According to the definition of the beta-function

$$B(x,y)=\int_0^1 t^{x-1}(1-t)^{y-1}\,\mathrm{d}t \tag{13}$$

we have

$$F(\omega)=a(n_0^2p^{-2}-1)/4\int_0^1 t^{\frac{n_0+\mathrm{i}\omega}{2p}-\frac{3}{2}}(1-t)\,\mathrm{d}t=$$

$$=a(n_0^2p^{-2}-1)/4\,\frac{2p}{(n_0+\mathrm{i}\omega-p)(n_0+\mathrm{i}\omega+p)}. \tag{14}$$

After substituting we have

$$\Phi(\omega)=\frac{ana_0^2(n_0^2-p^2)}{[\omega^2+(n_0-p)^2][\omega^2+(n_0+p)^2]}. \tag{16}$$

The power spectrum described by equation (16) has in the region of low frequencies the form

$$\Phi(\omega)_{\omega\to 0}=\frac{ana_0^2}{2k^2} \tag{17}$$

and is frequency independent. In the region of high frequencies it decreases proportionally to ω^{-4}. The power spectrum (16), together with the spectrum (5) and for comparison also with the power spectrum of the pulses of exponential shape, is shown in Fig. 1. As can be seen from this figure the behaviour of the power spectrum apparently depends on the shape of the Barkhausen pulses.

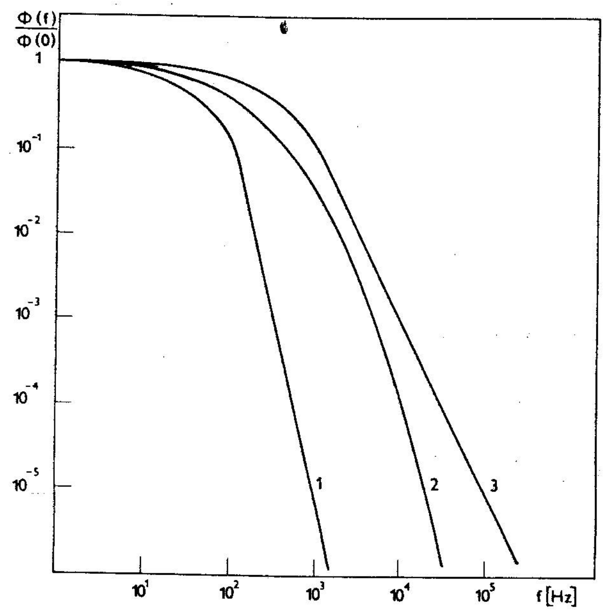

Fig. 1. The behaviour of the relative spectrum of the Barkhausen noise for different shapes of the elementary Barkhausen pulses. Curve 1 represents the spectrum, as given by equation (16), curve 2 is given by equation (5) and curve 3 represents the power spectrum of the pulses of the exponential shape ($\varepsilon(t) = a e^{-t/\alpha}$). The time constant α is in every case $\alpha = 10^{-3}$ sek.

IV. CONCLUSION

We have shown above that the course of the power spectrum of the Barkhausen noise is significantly influenced by the shape of the elementary Barkhausen pulses. This result may be ov considerable importance ib the interpretation of an experimentaly observed power spectrum of the Barkhausen pulses. Finally we note that analogical calculations can be made for the case of the correlated Barkhausen pulses.

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