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THE STUDY OF POWER SPECTRA OF THE BARKHAUSEN NOISE IN THE COURSE OF THE CYCLIC ASYMMETRICAL MAGNETIZATION REVERSAL OF FERROMAGNETIC SAMPLES

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The present work is the study of the influence of the asymmetrical magnetization reversal of a metal ferromagnetic sample on the shape of the power spectrum of the Barkhausen impulses. It has been found that in the course of the asymmetrical magnetization reversal the mutual correlation of the impulses changes and due to this change the shape of the spectrum also changes.

I. INTRODUCTION

The Barkhausen effect, as it was shown in a number of papers for example [1—4], is an effect of a statistical character. It was found that a fluctuation of the number of impulses registered in the process of the sample magnetization reversal takes place, that the time separation of the successive jumps fluctuates (fluctuation of the critical field) and that the shape and the width of the registered impulses fluctuates, too. All these facts indicate that it will be useful to apply statistical methods to the study of the Barkhausen effect. The information about the investigated effect will not be conveyed by shape, amplitude and the time interval between the individual impulses, but by the frequency course of the power spectrum of these impulses. From the shape of the measured power spectrum we can obtain statistically averaged data about the characteristic values of the registered Barkhausen impulses. In our work we have investigated the power spectrum of the Barkausen impulses originating in the course of the asymmetrical magnetization reversal of the Ni and Fe samples. Our main objective was to determine, how the shape of the power spectrum changes in dependence upon the number of the magnetizing cycles and upon temperature. Our results should contribute information about the processes connected with the asymmetrical magnetization reversal.

II. METHOD OF STUDY

II. 1. Frequency course of the power spectrum

As mentioned above, we have investigated the power spectrum of the Barkhausen impulses registered in the process of the assymmetrical magnetization reversal of metal ferromagnetic samples. It is very difficult to derive the analytical expression of the power spectral function of the Barkhausen impulses, because it is necessary to take into account a very large number of various experimentally observed facts. One of the most important among them is the fact that the elementary Barkhausen impulses form clusters. This fact was observed for example by Bittel and Westerboer [5]. The paper [6] pointed out the formation of clusters during the magnetization reversal of the ferrite samples. Lütgemeier [7] showed that the presence of clusters had a strong influence on the shape of the power spectrum. P. Mazzetti [8, 9] derived — using some simplifying asumptions — the form of the power spectrum of the correlated impulses. He supposed a series of exponential impulses with uniform amplitudes, whose mutual distances were distributed according to the Sawada distribution. Under these assumptions he obtained for the frequency course of the power spectrum the expression

$$\Phi(\omega) = \varphi(\omega)\left[1 + \frac{2\varrho}{1 + (\varrho\omega)^2}\right] \tag{1}$$

where $\varphi(\omega)$ is the spectral function of the statistically independent impulses and ϱ is the average number of pulses in one cluster.

The spectral function described by expression (1) has in the region of low frequencies the following course $\Phi(\omega) \approx 2\varrho\varphi(\omega)$. In the region of medium frequencies it decreases proportionally to ω^{-2} and at high frequencies it turns into the function $\varphi(\omega)$. Storm [10] pointed out the possibility of the originating of the frequency independent part in the power spectrum, in which the spectrum intensity is determined by the course of the function $\varphi(\omega)$. However, such a plateau has not been observed yet. The possible reason may lie in the fact that the spectra were investigated only up to the frequency of about 10^4 Hz. A more definite answer to this question may be provided only by measurements at higher frequencies, where the occurrence of a plateau is expected.

II. 2. Experimental apparatus

Measurements were carried out with an apparatus described in [17] completed by a frequency analyzer consisting of nine narrow-band amplifiers. The ampli-

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fiers were set at frequencies of 0.9 kHz, 2 kHz, 4 kHz, 8 kHz, 16 kHz, 32 kHz, 64 kHz, 128 kHz and 450 kHz. The rectified signal from amplifier was led either to a voltage meter or to memory elements controlled by an external pulse. In both cases it was possible to register the shape of the power spectrum in an arbitrary point of the minor hysteresis loop.

Measurements were performed on two annealed polycrystalline wire Fe and Ni samples. The starting point for the asymmetrical magnetization reversal was the remanent state. The sample was subjected to a cyclic asymmetrical magnetization reversal between two values of the external field H_A and $H_B = 0$. (Fig. 1).

The intensity of the external field H_A was 15.4 Oe for the Ni sample (i.e. 2.2 H_c) and 9.4 Oe for the Fe sample (i.e. 1.8 H_c). The magnetizing frequency was 0.16 Hz (Ni sample) or 0.045 Hz (Fe sample), respectively.

III. EXPERIMENTAL RESULTS

The power spectral function of the Barkhausen pulses was registered in the process of the sample magnetization reversal along the upper branches of the asymmetrical loops (branch 1 in Fig. 1). The results given in the following are for the value of the external field equal to H_c of the given sample.

The course of the power spectrum for the Ni sample magnetized at the temperature of 209 K is shown in Fig. 2. The dependence A is for the first cycle and the dependence B for the tenth cycle of the asymmetrical magnetization reversal. It is seen that both spectral functions differ at higher frequencies (from about 8 kHz) only as to the intensity, but not as to the shape. The shape is different only in the region of low frequencies, where the dependence A decreases more rapidly than the dependence B. A similar dependence of the power spectrum upon the number of the magnetizing cycles, but even more apparent, has been observed at the temperature of 77.4 K (Fig. 3).

In contrast to the former case a frequency independent part of the spectrum (plateau) from about 400 kHz is appearing here.

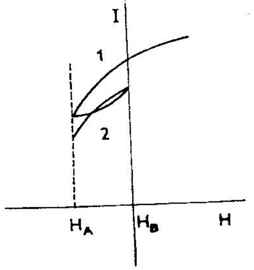

Fig. 1. The diagram of the asymmetrical magnetization reversal.

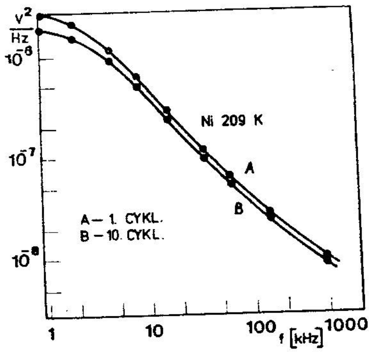

Fig. 2. The power spectrum of the Barkhausen pulses (Ni sample, 209 K).

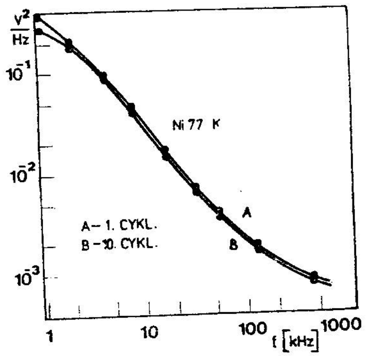

Fig. 3. The power spectrum of the Barkhausen pulses (Ni sample, 77.4 K).

The results of the measurements on the iron sample are shown in Figs. 4 and 5. Fig. 4 shows the power spectrum for the first (dependence A) and for the tenth (dependence B) magnetizing cycle at room temperature. These dependences are quite different from those observed on the nickel sample. The shape of the spectrum is different not only at low frequencies, but also at high frequencies. Only in the middle part of the spectrum approximately the same decrease has been observed, proportional to $f^{-1.8}$. In the region of low frequencies a local maximum appears in the course of the power spectrum, which becomes more apparent with the number of magnetizing cycles. Fig. 5 shows analogous depencences for the sample temperature 77.4 K (dependence A for the first, B for the fifth nad C for the tenth cycle of the asymmetrical magnetization reversal). Fig. 6 and 7 show the temperature dependence of the spectrum for the first (Fig. 6) and for the tenth cycles (Fig. 7).

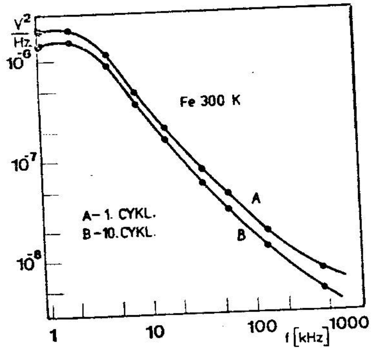

Fig. 4. The power spectrum of the Barkhausen pulses (Fe sample, 300 K).

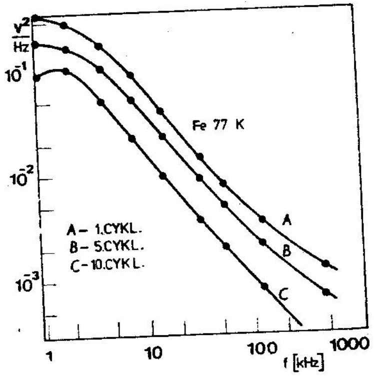

Fig. 5. The power spectrum of the Barkhausen pulses (Fe sample, 77.4 K)

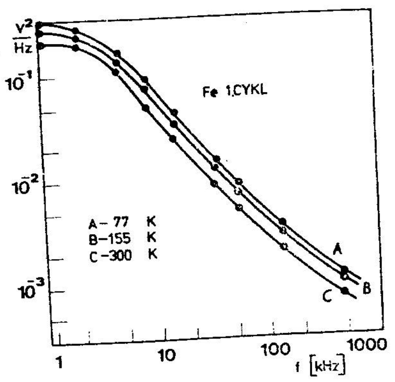

Fig. 6. The temperature dependence of the power spectrum of the Barkhausen pulses (Fe sample, first cycle).

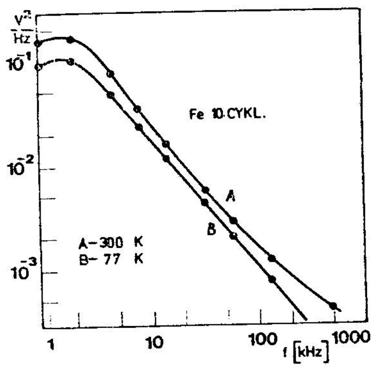

Fig. 7. The temperature dependence of the power spectrum of the Barkhausen pulses (Fe sample, 10^{th} cycle).

IV. DISCUSSION

Results given in the preceding chapter show that the frequency course of the power spectrum of the Barkhausen pulses has in all the investigated cases been dependent upon the number of the magnetizing cycles. The more rapid decrease of the spectrum in the region of low frequencies for the first magnetizing cycle indicates that the average width of the Barkhausen pulses decreases with the number of the magnetizing cycles. It can be deduced from Fig. 3, in which the frequency independent part of the spectrum is already apparent, that the narrowing of the impulses is — in the case of the Ni sample — caused by a decrease of the average number of the elementary Barkhauses pulses in one cluster. The more rapid decrease of the spectrum at a lower temperature indicates that the average width of the Barkhausen pulses increases with the decrease of temperature. This fact is connected with the increase of the relaxation times of eddy currents with a decreasing temperature of the metal sample.

The situation is more complicated in the case of the iron sample (Fig. 4 and 5). The more rapid decrease of the spectrum for the first magnetizing cycle at room temperature is observed only at a frequency of about 2 kHz. At lower frequencies a local maximum appears in the spectrum. Such an anomalous behaviour of the spectrum has not been sufficiently explained yet, even though a decrease in the region low frequencies has been observed by a number of authors (e. g. [11] and [12]). Mazzetti and Montalenti [13] have put this decrase into connection with the changes of the sample demagnetization factor. However, this explanation cannot be accepted in our case, because the decrease increases with the increasing number of the magnetizing cycles, the sample geometry remaining of course unchanged. The explanation given by the same authors in papers [9, 14, 15] and connecting the decrease of the spectrum with the space correlation of the Barkhausen pulses seems to be more likely.

More apparent changes of the rate of the spectrum decrease at low frequencies may be observed at the sample temperature of 77.4 K. However, also in this case a local maximum appears in the spectrum during the tenth cycle. This result indicates again that the cause of the spectrum decrase at low frequencies cannot be connected with the sample geometry.

From the observed course $\Phi(\omega)$ there can be estimated — using equation (1) — the approximate number of impulses in one cluster. The average number of impulses ϱ varied in our case from 10^2 to 10^3. Considering that according to Storm [10] the elementary volume whose magnetization is reversed by one irreversible displacement of the domain wall is $v_{el} \leqslant 5 \times 10^{-11}$ cm^3, then for the region whose magnetization is reversed by one registered Barkhausen pulse (correlated cluster) we obtain the value $\varrho \ v_{el} \leqslant 5 \times 10^{-8}$ cm^3. This value is in good agreement with the data given in [16] and [17]. These works, based on the study of the amplitude distribution of the registered Barkhausen pulses, give for $\varrho \ v_{el}$ the interval $8 \times 10^{-9} > \varrho \ v_{el} > 2.8 \times 10^{-11}$ cm^3 [17] and for the average volume whose magnetization is reversed the value 10^{-9} cm^3 [16]. A more accurate estimation of the mentioned volumes and of the number of pulses in one cluster is difficult, because in our measurements the apparent plateau in the spectrum has been observed only for the Ni sample at 77.4 K and for iron at 300 K.

The temperature dependence of the power spectrum of the Barkahusen pulses originating in the course of the cyclic asymmetrical magnetization reversal of the iron sample is shown in Figs. 6 and 7. It can be seen that the spectrum intensity in the first magnetizing cycle is the highest at a temperature of 77.4 K. In the tenth cycle the situation is reversed, the highest intensity of the spectrum is at room temperature and the lowest for 77.4 K. This indicates that the intensity of the spectrum as well as the number and the magnitude of the elementary displacements of the domain walls decreases very rapidly with an increasing number of the magnetizing cycles at this temperature. This fact indicates further that the mechanism of the processes taking place in the sample in the course of the asymmetrical magnetization reversal is very sensitive to the shape of the distribution of the critical fields of the irreversible elementary magnetizing processes, which changes with the temperature.

As already mentioned, in the process of the asymmetrical magnetization reversal a decrease of the time constant of the registered Barkhausen pulses take place. This may be caused partly by the decrease of the number of the elementary Barkhausen pulses in one cluster and partly by the decrease of the time constant of the relaxation processes connected with the realization of the Bakrhausen jump. The time constant of the relaxation processes is in the case of the conducting samples represented mainly by the time constant of the eddy currents τ_e, which is (e.g. according to [21]) equal $\tau_e = 4\pi\mu\sigma$, where μ is the reversible permeability and σ is the electrical conductivity of the sample. The decrease of τ_e indicates therefore that μ also decreases.

The decrease of the number of impulses in one cluster as well as the change of the spectrum shape in the region of low frequencies in dependence upon the number of the magnetizing cycles indicates that in the process of the asymmetrical magnetization reversal the change of the mutual correlatio of the Barkhausen pulses take place. The mechanisms of this correlation may be various, 1) a simple electrodynamic influence of the time varying magnetic dipole on the neighbouring domains [18], 2) a coupling by stray fields [4], and 3) a coupling between succesive positive and negative jumps [19]. This last mechanism is supported also by the results of paper [20], where it has been shown that in the process of the asymmetrical magnetization reversal appreciable changes in the occurrence of negative Barkhausen jumps take place.

REFERENCES

[1] Tyndall E. P. T., Phys. Rev. *24* (1924), 439.
[2] Förster F., Wetzel H., Zs. f. Metallkunde *33* (1941), 115.
[2] Steward K. H., J. Phys. Rad. *12* (1951), 325.
[4] Kolačevskij N. N., *Magnitnyje šumy.* Nauka. Moskva 1971.
[5] Bittel H., Westerboer I., Ann. Phys. *4* (1959), 203.
[6] Zentko A., Czech. J. Phys. *B 19* (1969), 1454.
[7] Lütgemeier H., Zs. Angew. Phys. *16* (1963), 153.
[8] Mazzetti P., Nuovo Cimento *25* (1962), 1322.
[9] Mazzetti P., Nuovo Cimento *31* (1964), 88.
[10] Storm L., Zs. Angew. Phys. *26* (1969), 91.
[11] Goronina K. A., Gračev A. A., Izv. VUZOV, Radiofizika *2* (1959), 581.
[12] Bonnefous J., Compt. Rend. Acad. Sci. *254* (1962), 1014.
[13] Mazzetti P., Montalenti G., *Proc. Inter. Conf. on Magnetism.* Nottingham 1964.
[14] Biorci G., Mazzetti P., L Elettrotechnica *48* (1961), 469.
[15] Mazzetti P., Montalenti G., L'Energia Elettrica *39* (1962), 562.
[16] Kolačevskij N. N., Fiz. met. i metalov. *11* (1961), 211.
[17] Zentko A., Hajko V., Czech. J. Phys. *B 18* (1968), 1026.
[18] Levin M. L., Pamjati A. A., *Andronova.* Izd. AN SSSR, Moskva 1955.
[19] Zentková A., Zentko A., Hajko V., Czech. J. Phys. *B 19* (1969), 650.
[20] Hajko V., Zentko A., Hučko L., Acta Phys. Slov. *23* (1973), 53.
[21] Zentková A., Fyz. čas. SAV *19* (1969), 203.

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