Fyzikálny časopis 19 (1969), No. 4

THE INFLUENCE OF THE GEOMETRY OF THE SPECIMEN ON THE FORM OF THE BARKHAUSEN PULSE

ANGELA ZENTKOVÁ, Košice

The paper presents a study on the effect of the geometrical size of the specimen and the position of the discontinuity relative to the search coil upon the shape of the induced pulse in the search coil. It has been found that both geometrical sizes and mutual distance of the coil and the site of origin of the Barkhausen jump considerably affect the shape and amplitude of the registered Barkhausen pulse.

INTRODUCTION

In all experimental works on the Barkhausen effect the voltage pulse induced in the search coil is the only carrier of information about processes proceeding inside the ferromagnet during the Barkhausen jump. The time course of this pulse has been examined by several authors as Elkock in paper [1], Rytow in paper [2] and Tebble, Skidmore, Corner in paper [3] and Polivanov, Roditchev, Ignatchenko in paper [4].

The authors of paper [1] and [2] considered the Brakhausen jump as the time change of the moment of the magnetic dipole located inside the ferromagnet. At first they considered the magnetic dipole as independent of time. By the solution of Poisson's equation and Laplace's equation, respectively, they obtained a distribution of the magnetic field of this dipole both inside and outside the ferromagnet. The flux of induction Φ in the coil has been obtained by the integration through the cross sectional area of the search coil. Interchanging the constant magnetic dipole for a time depending one for Φ in the expression, we obtained the expression for a time change of the flux in the search coil, corresponding to the induced voltage.

Proceeding in such a way, however, is mathematically very complicated. The expression for Φ is given by the infinite integral of a complex expression, containing the Bessel functions $\mathscr{I}_0$ and $\mathscr{I}_1$ of the imaginary argument and the Mac Donald Functions. Rytow obtained a result in the form of elementary functions only for $z \gg a$, where z is the coordinate of the point in which the expression for Φ is evaluated and a is the radius of the specimen. But in fact, the largest contribution is for $z = 0$ so that the result is only a crude approximation of the real state. The most important drawback, however, is that the influence of the dynamic effect of the eddy current, which must not be neglected in a metal ferromagnet, is not being considered.

R. S. Tebble et al. [3] and K. M. Polivanov et al. [4] chose another approach. These authors considered that the magnetic moment $m_0 = 2 I_s v_0$ changes in the region of the discontinuity of the volume v_0 during the jump.[1]

This change of the moment corresponds to the change of the induction by ΔB on the sectional surface of the jump region s_0 expanding in the ferromagnet.

The equation describing the propagation is as follows

$$\nabla^2 B = \gamma \frac{\partial B}{\partial t}, \tag{1}$$

where $\gamma = 4\pi\mu\sigma$, μ, σ are the reverse permeability and the electrical conductivity of the specimen.

The solution of this equation gives the time and spatial distribution of the induction B in the specimen. By integration through the cross sectional area of the specimen we get the induction flux in the specimen and by derivation of the flux according the time we get the rate of the change of flux $\frac{d\Phi}{dt}$, corresponding to e. m. f. induced in the search coil. This solution respected both the influence of the eddy currents and that of the electric and magnetic properties of the specimen. In addition to this the authors of papers [3] and [4] showed that the size and shape of the pulse induced in the search coil depend on the radial coordinate of the position of discontinuity. Still unsolved is the question considering the location of the site of the discontinuity in the axial direction, i. e. along the distance between the position of the discontinuity and the seach coil.[2] (Fig. 1.)

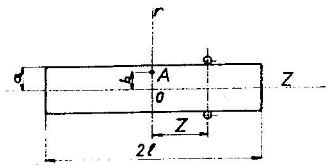

Fig. 1. Schematic illustration of the site of the origin of the Barkhausen jump.

[1] For the sake of convenience the region of the discontinuity is considered as a prism with the cross section s_0 and the length $2 z_0$.

[2] The search coil is here represented by a single turn. The results derived for such a coil will approximately be valid under conditions as shown in section 5 also for narrow search coils in which $\varepsilon(t)$ can be considered as independent upon the z-coordinate in the whole search coil.

The influence of geometrical sizes has not been further investigated. These tasks will be solved in the present paper.

FORMULATION OF THE PROBLEM

We shall start from the same equation (1) as the authors of papers [3] and [4]. Since we, however, have to express spatial dependencies, we shall consider the magnetic induction B a constant depending upon three spatial coordinates. Then the solution of this equation in cylindrical coordinates as demonstrated in paper [5] will be as follows

$$B = B' - \sum_{n=0}^{\infty}\sum_{n'=0}^{\infty}\sum_{k=1}^{\infty} \frac{2\delta\Phi_0 \sin\left(n' + \frac{1}{2}\right)\frac{\pi}{l} z_0}{\left(n' + \frac{1}{2}\right)\pi^2 a^2 \mathcal{J}^2_{n+1}(\lambda_{nk})} \mathcal{J}_n\left(\lambda_{nk}\frac{b}{a}\right) \times \tag{2}$$
$$\times \cos n\vartheta \mathcal{J}_n\left(\lambda_{nk}\frac{r}{a}\right)\cos\left(n' + \frac{1}{2}\right)\pi\frac{z}{l}\exp\left\{-\frac{t}{\gamma}\left[\frac{\lambda^2_{nk}}{a^2} + \left(n' + \frac{1}{2}\right)^2\frac{\pi^2}{l^2}\right]\right\}.$$

B' is the stable value of the magnetic induction in the whole specimen after the realization of the Barkhausen jump, $\delta = 1$, for $n = 0$, $\delta = 2$, for $n > 0$, $\mathcal{J}_n$ is a Bessel function of the n-th order, λ_{nk} is the k-th root of the equation $\mathcal{J}_n(\lambda_{nk}) = 0$, a is the radius of the specimen, $2\,l$ the length of the specimen, r, ϑ, z are the coordinates of the point at which the value of the expression for B has been evaluated. Similarly, for the e. m. f. induced in a single turn of the search coil, located at the distance z from the site of discontinuity the following relation has been derived in paper [5]

$$\varepsilon_z(t) = -\frac{4\Phi_0}{\pi\gamma}\sum_{n'=0}^{\infty}\sum_{k=1}^{\infty}\frac{\sin\left(n' + \frac{1}{2}\right)\pi\frac{z_0}{l}}{\left(n' + \frac{1}{2}\right)\lambda_k \mathcal{J}_1(\lambda_k)}\mathcal{J}_0\left(\lambda_k\frac{b}{a}\right) \times \tag{3}$$
$$\times \cos\left(n' + \frac{1}{2}\right)\pi\frac{z}{l}\left[\frac{\lambda_k^2}{a^2} + \left(n' + \frac{1}{2}\right)^2\frac{\pi^2}{l^2}\right]\exp\left\{-\frac{t}{\gamma}\left[\frac{\lambda_k^2}{a^2} + \left(n' + \frac{1}{2}\right)^2\frac{\pi^2}{l^2}\right]\right\}.$$

Thus we can examine the dependence of this expression upon the parameters occurring in it, such as the geometrical sizes of the specimen (radius a, length $2\,l$) and the distance between the site of the origin of the jump and the search coil (coordinate z).

DEPENDENCE OF $\varepsilon(t)$ UPON THE GEOMETRICAL SIZES OF THE SPECIMEN

Let us assume the origin of the Barkhausen jump in point A with the coordinates $r = b$, $\vartheta = 0$, $z = 0$ (Fig. 1). The search coil will be located at the distance z from this point. Thus with the change of the length of the specimen the parameters z/l and z_0/l will be changed in the expression for $\varepsilon(t)$. Figure 2 illustrates the course of $\varepsilon(t)$ for various values of this parameter, which correspond to the different lengths of the specimen. Curve 1 is for $z/l = z_0/l = 10^{-3}$, curve 2 for $z/l = z_0/l = 5 \times 10^{-4}$, curve 3 for $z/l = z_0/l = 10^{-5}$. It is evident that the amplitude of the induced pulse increases with decreasing length of the specimen and the pulse peak is reached within a shorter time after the realization of the jump. This is related to the limited effects of eddy currents through the decrease of the specimen volume.

EFFECT OF THE DISTANCE BETWEEN THE POSITION OF THE DISCONTINUITY AND THE SEARCH COIL UPON $\varepsilon(t)$

In this case we shall consider the length of the specimen as constant and calculate the $\varepsilon(t)$ course for various distances z. For the various distances between the site of the jump origin and the search coil certain values of the

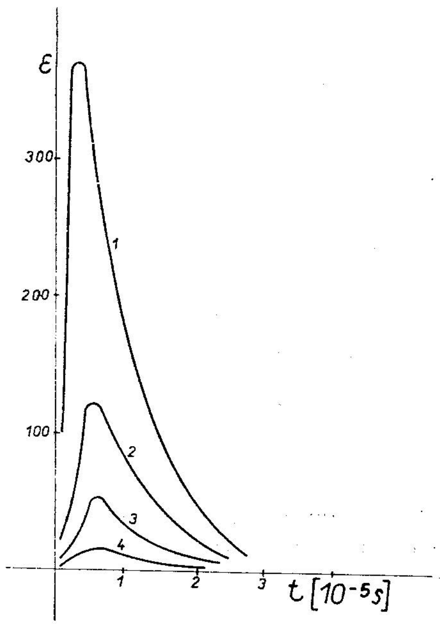

Fig. 2. Time course of $\varepsilon(t)$ for different values z/l and z_0/l.

parameter z/l in equation (3) will be obtained. The parameter z_0/l remains constant and $z_0/l = 10^{-5}$. The results have been illustrated in Figure 3, where curve 1 is for $z/l = 10^{-5}$, curve 2 for $z/l = 10^{-3}$, curve 3 for $z/l = 5.10^{-3}$ and curve 4 for $z/l = 10^{-2}$. Here, the same as in the previous case, the courses of the single curves differ from each other. With the increasing distance z the amplitude of the pulse in the search coil will decrease and its peak shifts to greater values of time. This shift becomes particularly evident when $z/l \to 1$, as may be seen in Figure 4, which is an illustration of the time course $\varepsilon(t)$ for $z/l = 0{\cdot}9$. Here $\varepsilon(t)$ reaches a maximum after $t = 2 \times 10^{-4}$ sec. from the moment of the real origin of the Barkhausen jump. The amplitude, however, is very small.

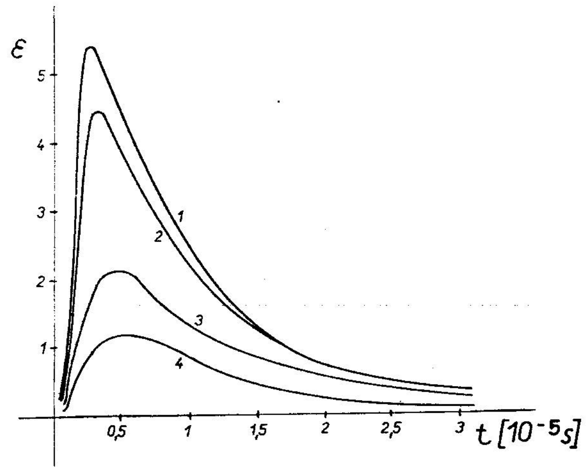

Fig. 3. Time course of $\varepsilon(t)$ for different values z/l at a constant z_0/l.

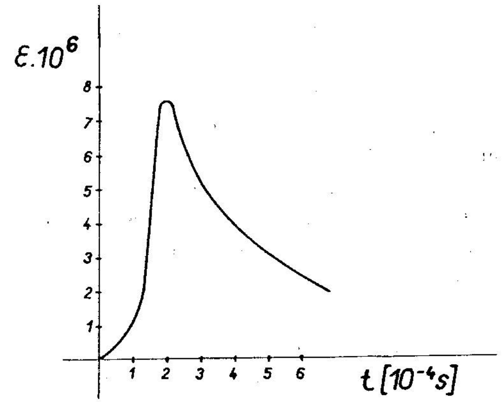

Fig. 4. Time course of $\varepsilon(t)$ for $z/l \to 1$.

The dependences illustrated in Figures 2, 3, 4 have been evaluated for the specimen with $\mu = 100$ and $\sigma = 10^6(\Omega\ \text{cm})^{-1}$. The parameter b/a has been chosen equal to 0·8. The choice of the numerical values z_0/l, z/l was determined by the condition of the rapid convergence of the row (3).

INFLUENCE OF SEARCH COIL SIZES

So far considerations have been limited to one turn search coils though such an abstraction may not always meet the requirements of the real physical experiment. It is therefore necessary to indicate the applicability of these results to real polyturn coils. The e. m. f. induced in such a coil is given by the integration of the expression (3) through the geometrical sizes of the coil. The shape of the induced pulse is therefore always affected by the geometry of the search coil. The smaller the size of the search coil the more will the result calculated from equation (3) approach reality. The search coil can be considered sizeless, if, within the allowed tolerance set by us, the function $\varepsilon(t)$ in the whole search coil can be considered independent on the z coordinate. Thus in a coil of a 0·1 cm length, wound on a specimen of a 25 cm length, and of a 0·1 cm diameter, the change $\varepsilon(t)$ along the coil will exceed 8 % for any distance between the site of the origin of the jump and the center of the search coil. If we consider that in experimental works only coils of an about 0·1 cm width are used — because of the small time constant — we can see that in these cases the results reported in sections 3 and 4 do well correspond to reality. For long coils, even if the dependence upon size and location of the site of the jump origin against the search coil is evident, this dependence will not be qualitatively similar to that in Figures 2, 3, 4.

EVALUATION OF THE RESULTS AND SUMMARY

From the above we may see that the time course of the pulse obtained at the output of the search coil, is — in addition to the electric and magnetic properties of the ferromagnet of the specimen — being affected also by a whole series of other agents. We indicated that an important part is played by the location of the discontinuity against the search coil and the geometrical sizes of the specimen. For two jumps, similar in size and originating at different sites of the specimen, we obtain different pulses in the search coil. It is therefore difficult to construct the registrated pulse amplitude distribution as it is done in some experimental works, since it is very difficult to find a rule according to which it would be possible unambiguously to assign the distribution of the

real sizes of the Barkhausen jumps according to the corresponding sizes of the changes of the magnetic moment m_0 during the jump to the measured amplitude distribution of the registered pulses. It will therefore not be possible to estimate the contribution of the Barkhausen jumps to the total change of the magnetization of the specimen by simple integration of the registered pulses amplitude distribution.

The results of this paper are in good agreement with some experimental observations. Thus A. M. Roditchev [6] examined the effect of the change of the demagnetization factor of the specimen on the total amount of registered pulses. The demagnetization factor changed with the change of the length of the specimen. At first sight these results would seem paradoxical. First the number of registered pulses increased with the increasing length of the specimen. This was to be expected since the volume of the specimen was increasing. The amount of pulses increased also when the specimen was longer than the search coil. With further increase of the length of the specimen, however, the number of registered pulses began to decrease, though, of course, the volume of the specimen was steadily growing. The author of paper [6] tried to explain this paradox by the change of the rate of the magnetic field increase in the specimen as a result of the change of the demagnetization factor of the specimen. Though the rate of the field change within the specimen certainly plays an important role (at a very quick rate some pulses may overlap and be registered as a single one), this effect should play a decisive role in the case of short specimens, when the demagnetization factor rapidly changes; in long specimens, where the demagnetization factor may be neglected, it should not appear at all. This has not been experimentally proved. The elucidation of the whole paradox may, on the basis of our results, be mainly looked for in the amplitude decrease of all jumps as a result of the specimen extension. Thus part of the pulses gets under the threshold of sensitivity of the measuring equipment and is not registered. The resulting number of registered pulses is the resultant of two contraversial requirements, i. e. the requirement of jump number increase with the specimen volume increase and amplitude decrease as a result of specimen extension, while keeping the other dimensions unchanged.

Finally the author wishes to thank Prof. T. Kolbenheyer and Prof. V. Hajko for valuable advice and discussions. I gratefully acknowledge also the assistance of O. Csala, who performed the numeric calculations on the computer MINSK 22 and wish to thank Mr. Z. Kubanyi for the drawings.

REFERENCES

[1] Elkock E. W., Proc. Leeds. Phil. Soc. *6* (1952), 1.

[2] Рытов С. М., ЖЕТФ *27* (1954), 307.

[3] Tebble R. S., Skidmore I. S., Corner W. D., Proc. Phys. Soc. *A 63* (1950), 739.

[4] Поливанов, К. М., Родичев, А. М., Игнатченко, В. А.: Физ. мет. и металов. *5* (1960), 774

[5] Zentková A., Zentko A., Hajko V., Czech. J. Phys. *B 19* (1969), 650.

[6] Родичев, А. М. *Магнитная структура феромагнетиков*. Материалы Красноярсково совэщаниа, Новосибирск 1960.

Received December 9th, 1968

Katedra teoretickej fyziky a geofyziky
Prírodovedeckej fakulty UPJŠ,
Košice