acta phys. slov. 40 (1990), No. 4

THE SHAPE OF INDIVIDUAL BARKHAUSEN IMPULSES IN AMORPHOUS AND CRYSTALLINE FERROMAGNETIC MATERIAL[1])

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The Barkhausen impulses induced in a pick-up coil during the magnetization reversal of some polycrystalline and amorphous ferromagnetic samples were investigated by a digital storage oscilloscope. The character of the measured impulses was compared with the course of the $E(t)$ function derived theoretically. It was found that the shape of a short individual impulses observed in our experiment corresponds relatively well to the given by theory. The obtained results were also compared with some previous experiments. The new evidence for the existence of the negative Barkahusen jumps was obtained and some possibilities of their origin are discussed.

I. INTRODUCTION

It is known that the voltage induced in the pick-up coil wound on a ferromagnetic sample magnetized by a slowly increasing external magnetic field is not a smooth function of this field but rather shows a structure composed of many individual impulses of various shape, amplitude and length. This effect is known as the Barkhausen effect and the individual impulses as the Barkhausen jumps or the Barkhausen impulses. The character of these impulses was theoretically analysed in many papers [1—5] with respect to various parameters. In some of them formulas describing the time dependence of the induced voltage $E(t)$ were derived. These expressions are considerably complicated containing many parameters which concern the material and the geometrical shape of the sample, the dimensions of the pick-up coil and the coordinates (site) of the origin of the Barkhausen jump in a sample. Moreover, they mutually differ depending on the used approximation, but the principal character is the same, e.g. — for the cylindrical samples the $E(t)$ is given by the sum of the exponential functions of time multiplied by the Bessel functions of the geometrical parameters.

[1]) Contribution presented at the 8th Conference on Magnetism, KOŠICE 29. 8.—2. 9. 1988

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While there are many theoretical papers analysing the shape of the Barkhausen impulse, there are on the other hand practically only few papers in which this problem was studied experimentally. A lack of the experimental studies of the individual $E(t)$ impulses is caused by rather involved experimental problems resulting from their small amplitude and length as well as from their statistical character. At present the electronics allows us to solve some of these problems and consequently to study the shape of the individual Barkhausen impulses. In this paper we present some preliminary results obtained on amorphous and polycrystalline ferromagnetic samples and compare them with results of other authors.

II. EXPERIMENTAL

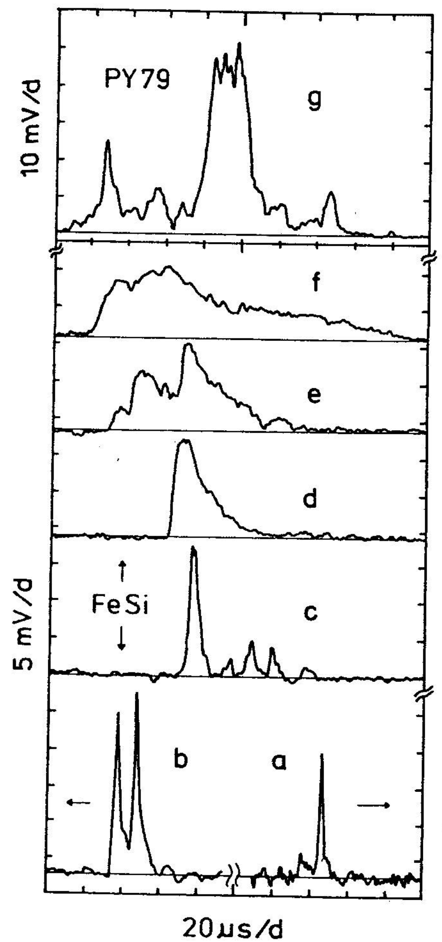
Stripes of polycrystalline 3 % SiFe transformer steel 20 cm long, 5 mm wide and 0.3 mm thick and amorphous ribbons of various composition, 20 cm long, 1—10 mm wide with a thickness of about 30 μm were used in our study. Also one sample of PY79 ribbon (200 × 10 × 0.05 mm) in the state before the final high temperature annealing was studied. The samples were magnetized in a long solenoid by a slowly increasing magnetic field linearly with time. The magnetizing current was generated by a 16 bit D/A convertor driven by a variable time base derived from a quartz crystal oscillator, which can be controlled by a LSI 11/23 minicomputer. The time of a single run on one branch of the hysteresis loop can be changed from 0.1 s to 80 min. In practice mainly the 4 min run was used.

As the theoretical investigations show, the amplitude and shape of the voltage impulse $E(t)$ induced in the pick-up coil is strongly influenced by the parameters of the pick-up coil, therefore for all measurements the same sensing coil with a relatively small number of turns (and consequently a small inductance, a small time constant) was used with 100 turns in a single layer of a 17 mm length. The signal from this coil was amplified in an op-amp based low noise two stage wideband preamplifier (from DC to 300 kHz) with an amplification of 40 dB. The output signal from this preamplifier with a noise level of 1.5 mV_{p-p} was analysed by a digital storage oscilloscope (IWATSU DS 6121). Impulses with an amplitude well above the noise level were recorded on the screen of the oscilloscope in a single sweep mode by a suitable setting of the triggering level and then recorded on the x—y plotter connected with the oscilloscope.

It was found that it is possible to observe the majority of the Barkhausen impulses in the steep part of the hysteresis loop. The individual impulses can be observed above all in the knees of the loop, whereas in the central part a large amount of impulses joined mostly into big clusters is usually generated.

III. RESULTS AND DISCUSSION

Typical examples of the observed Barkhausen impulses for amorphous and polycrystalline samples are given in Fig. 1 to Fig. 4. In the polycrystalline FeSi samples we have observed various shapes of individual impulses from very short peaks (see 1a, 1b), medium length impulses (see 1c, 1d) up to very long impulses (1e, 1f). Whereas the short impulses are without any doubt really individual or the individual parts can easily be distinguished (1b, 1c), for long impulses (1e, 1f) it is difficult to decide whether it is really the case of a single long impulse or some cluster of overlapping impulses. In Fig. 1e there seems to be a cluster



◄ Fig. 1. Barkhausen impulses in polycrystalline samples. FeSi: transformer steel sheet 5 × × 0,3 × 200 mm. PY79: permalloy ribbon 10 × × 0,05 × 200 mm in state before a final annealing.

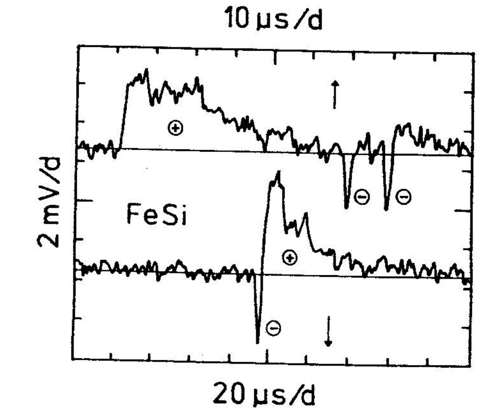


Fig. 2. Positive and negative Barkhausen impulses in polycrystalline FeSi samples.

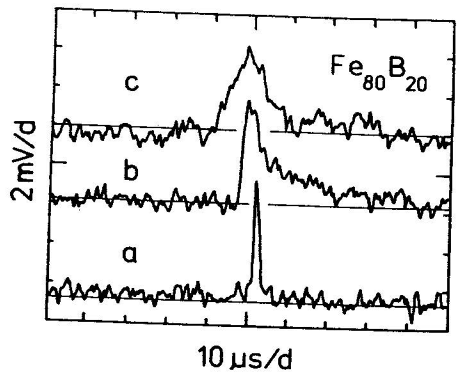


Fig. 3. The shape of the individual Barkhaussen impulses in amorphous $Fe_{80}B_{20}$ ribbon (1 × 0,03 × 200 mm).

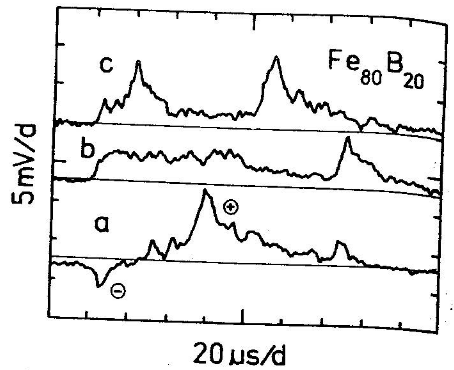


Fig. 4. Clusters of the Barkhausen impulses in amorphous $Fe_{80}B_{20}$ ribbon.

of three or four individual impulses similar to that shown in Fig. 1c. For the impulse in Fig. 1f, it is not so simple to find individual parts. An example of a very complicated cluster of various peaks with relative high amplitudes observed on the PY79 sample is given in Fig. 1g.

Besides the majority of impulses with a polarity corresponding to the overall change in magnetization some impulses with an opposite sign were also observed. In Fig. 2 the most interesting situations are given where both positive and negative Barkhausen impulses for the FeSi samples have been recorded simultaneously. The existence of the negative Barkhausen jumps was already presented in the preceding papers [6], [7], where the induced voltage in a pick-up coil was studied and was also proved by the Kerr effect studies [8], but this new evidence is much more unambigous and at the same time gives us also more information on the relationship between the positive and the negative Barkhausen jumps as we show later in the conclusions.

The Barkhausen impulses observed in the amorphous $Fe_{80}B_{20}$ samples are shown in Fig. 3 and 4. Due to the low amplitude of the impulses, especially in Fig. 3, a noise of the preamplifier is more distinct but there is not a basic difference in the character of the impulses in comparison with those for polycrystalline FeSi. The very short peak from Fig. 3a has its counterpart in Fig. 1a and, likewise, the impulse from Fig. 3b corresponds to that in Fig. 1d. Further, impulses with a much more complicated structure (see Fig. 4) have also been observed. The course of $E(t)$ shown in Fig. 4a gives evidence that the negative Barkhausen jumps do exist also in amorphous ferromagnetic materials.

In order to have the possibility to compare the experimental and the theoretical course of the $E(t)$ impulses, in Fig. 5 the theoretical shapes of $E(t)$ taken from [5] are given. Those shapes were calculated for a cylindrical nickel sample

with a diameter of R_0 for various distances R of the site of the Barkhausen jump from the axis of the cylinder. It can be noticed that the shape of the individual Barkhausen impulses observed in our study is in good agreement with the shape of $E(t)$ derived theoretically. We can conclude that the observed sharp peaks correspond to the Barkhausen jumps that take place near the surface of the sample and the broad ones to those from the central part of the sample. For complicated clusters of impulses such a simple and clear explanation is impossible. Especially the very long and flat course of $E(t)$ in Fig. 4b is not so well explainable as the cluster of shorter impulses.

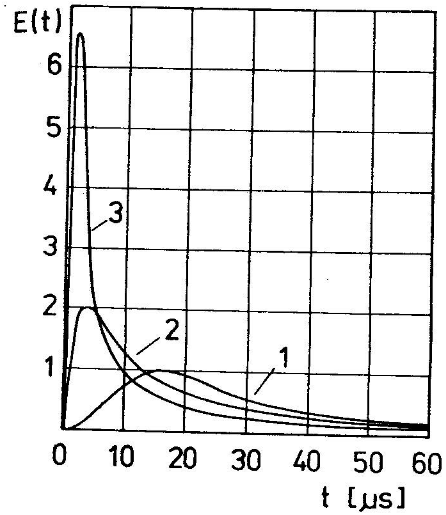


Fig. 5. A theoretical shape of the Barkahusen impulse as a function of a distance R from the axis of a cylindrical Ni sample with a radius R_0. 1 — $R/R_0 = 0.2$, 2 — $R/R_0 = 0.6$, 3 — $R/R_0 = 0.8$. From [5].

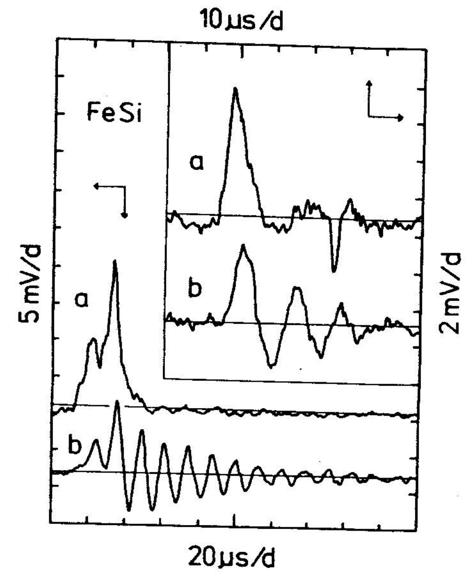


Fig. 6. The influence of the parameters of a pick-up coil on a shape of an individual Barkhausen pulse. (a) — low inductance coil (tightly wound on a sample), (b) — high inductance coil (wound on a tube with diameter of 2 cm).

Our results are in strong disagreement with those of paper [9]. P. J. Coyne and J. J. Kramer measured the $E(t)$ impulses using a high impedance multiturn (5000 turns) pick-up coil damped with a suitable resistor. The impulses were recorded on a wideband instrumentation recorder (250 kHz) and afterwards analysed by a digital technique. They observed not simple unipolar impulses but rather oscillations with a decreasing frequency and in general a decreasing amplitude in each succeeding half cycle. They called the negative portion of the impulse "the negative Barkhausen impulse" and so they connect the positive and the negative Barkhausen jump into a single event. In their next paper [10] Conye and Kramer explain the observed negative portion of the Barkhausen impulse by an influence of the low frequency cut-off of the recorder. Nevertheless, the 500 turn pick-up coil used in [9] had probably a very long time constant and therefore worked in the ballistic regime for which the voltage on the pick-up coil corresponds rather to an integral of $E(t)$ (i.e. to the magnetic flux through the sensing coil) and therefore could not be compared with a theoretical expression for $E(t)$ (i.e. for the time derivative of the magnetic flux).

Our experience with the equipment for the study of the Barkahusen jumps shows that many parameters of the pick-up coil and amplifiers influence very strongly the shape of the observed impulses. As an example in Fig. 6 we present impulses measured by two channel systems with identical amplifiers and two coaxial 100 turn sensing coils differing only in a diameter of the winding both positioned in the centre of the sample. The courses labelled by letter "a" are for the coil tightly wound on a sample and those labelled by "b" for the coil wound on a tube with a the diameter of 2 cm. It can be seen that instead of unipolar impulses (positive or negative) damped oscillations arise for the "b" coil and the really existing independent negative impulse disappears in oscillations caused by the preceding positive impulse.

IV. CONCLUSIONS

Our study of the voltage impulses induced in a pick-up coil with sufficiently low impedance by means of an apparatus with a bandwidth ranging from DC to hundreds of kHz shows that:

— the observed impulses are both individual and joined in clusters and the character of these impulses is only slightly different for the studied polycrystalline and amorphous samples.
— the shapes of many individual impulses correspond to those derived theoretically and the lengths of the investigated impulses are smaller than the lengths obtained in previous experiments of other authors.
— negative Barkhausen jumps really exist in amorphous and crystalline materials as it was already proved in previous papers [6—8], but the mutual relation between the positive and the negative jumps is not so simple as it has been assumed so far. As it can be seen in Fig. 2, the positive jumps can be initialised by a preceding negative jump. On the other hand also individual negative Barkhausen impulses separated from other (positive or negative) ones by hundreds of microseconds were observed, therefore the origin of the negative Barkhausen jumps cannot be only in a coupling with the positive jump by a local magnetic field of eddy currents but another mechanism must also exist, as we had already assumed in our previous paper [11] for the case of the Barkhausen impulses observed in an aftereffect experiment.
— in agreement with the authors of [10] we emphasize that the parameters of the used apparatus influence very drastically the character of the observed Barkhausen impulses. For the study of the individual Barkhausen impulses $E(t)$ an apparatus with a rather broad frequency response ranging from DC to minimally hundreds of kHz (or better up to 1—10 MHz) must be used and the time constant of the sensing coil must be as small as possible. Otherwise, the observed shapes of $E(t)$ cannot be attributed to the studied samples because they are considerably distorted by the used equipment. For the same reason the observations of the Barkhausken impulses realized on various equipments with insufficient parameters cannot be compared.

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Received November 1st, 1988
Accepted for publication March 3rd, 1989

ФОРМА ИНДИВИДУАЛЬНЫХ ИМПУЛЬСОВ БАРКХАУСЕНА В АМОРФНЫХ И КРИСТАЛЛИЧЕСКИХ ФЕРРОМАГНИТНЫХ МАТЕРИАЛАХ

С помощью инфрового накопительного осциллоскопа были исследованы импульсы Баркхаусена, индуцированные в захватывающей катушке во время изменения магнетизации. Характер измеренных импульсов сравнивается с функцией $E(t)$, полученной теоретически. Показано, что для коротких индивидуальных импульсов, наблюдаемых в эксперименте, имеет место относительно хорошее соответствие с теоретическими предсказаниями. Полученные результаты сравниваются также с результатами предыдущих экспериментов. Приведенные экспериментальные данные свидетельствуют о негативных скачках Баркхаусена.