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BARKHAUSEN-NOISE AND MECHANICAL SENSITIVITY IN FINEMET-TYPE MATERIALS

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Measuring technique, developed at our Laboratory for the investigation of ferromagnetic industrial materials, experimental results obtained and their analysis are reviewed. The magnetic properties (permeability, mechanical sensitivity) of as received and heat treated Finemet type ribbons ($Fe_{75}Si_{15}NbBCu$) were measured with common industrial equipments. The above properties were correlated with magnetic Barkhausen noise parameters. The distributions of peak area A and peak noise energy E were analyzed and it was found that distribution of the noise parameters $P(x)$ (where $x = A$ or E), were in good agreement with the theory of self organized criticality (SOC), satisfying power laws in the form $P(x) \sim x^{-\beta}$. Useful correlation between the noise parameters and the mechanical sensitivity has been established. The noise did not considerably depend on the other parameters of ribbons.

K e y w o r d s : Barkhausen noise measurement, mechanical sensitivity, finemet-type alloys

1 INTRODUCTION

Magnetic Barkhausen noise (MBN) measurement is an effective probe to characterize the magnetization features of ferromagnetic materials. The two main research/application areas are: evaluation of statistics of the peak distributions [1-6] and applications of the MBN for characterization industrial soft and hard magnetic alloys. The scaling properties, universality classes and stress effects on the magnetic noise spectra of finemet type alloys in the focus of our investigations. Products made from FINEMET ribbons are one of the most frequently used soft magnetic materials for industrial and everyday applications, ie ground fault current circuit breakers, chokes, filters, transformers, *etc*.

Our aim was to evolve a measuring technique for the investigation of ferromagnetic materials that can be used in the industry. Previously it was found from TEM, DSC and X-ray investigations that, during isochronal heat treatments, the volume fraction of Fe particles in the nanocrystalline composite FINEMET material were gradually increased with increasing temperature from zero up to about 70% in the 673-873K temperature interval [8], [9].

In our more recent paper [10] we found a useful correlation between the MBN statistics and the mechanical sensitivity parameter of the finemet type ribbons. The magnetic permeability, the temperature/ mechanical sensitivity were measured and the distributions of different noise parameters were analyzed to determine the optimum state of end products and also to improve the quality control. Our results were in agreement with recent publications [2-7] and, in addition, show a useful correlation between the mechanical sensitivity parameter and the noise level or the full dissipated energy of MBN.

In this communication we summarize our result in developing the measuring technique and present the most important features of the above mentioned correlation between the mechanical sensitivity and Barkhausen noise parameters.

2 THEORY

The physical background of the correlation between the noise level-dissipated energy and mechanical stress can be as follows. In many amorphous and partially nanocrystallized magnetic structures the magnetic anisotropy factor K can be rather small and the magnetic structure of this alloys differs from the classical domain pattern, characteristic for the hard magnetic alloys. In ferromagnetic materials the change of domain structure under external field is not continuous. In most models for Barkhausen effect the domain walls between the neighbouring domains can step at a critical field. If the average anisotropy constant $\langle K \rangle$ is small, for example in the case of finemet type materials and other soft metallic glasses, the average wall thickness can be large and rather a continuously curling magnetic momentum structure can be formed [11], [12]. Furthermore, the mechanisms responsible for magnetic anisotropy also give rise, across magnetoelastic coupling, to magnetostriction and, which is more relevant here, to stress induced anisotropy [13]. Local deviations of the anisotropy factor (or the stress induced anisotropy) from the nearly $\langle K \rangle$ can cause locally (*eg* in the near-surface layers, or around the nanocrystalline precipitates) more sharp domain-wall boundaries and more appreciable Barkhausen noise effect. In fact the well known

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macroscopic correlation between the RMS (root mean square) value of the MBN and the uniaxial stress level in macroscopically homogeneous samples [14] is also based on the stress induced anisotropy effect. The nature and the strength of the above local deviations in an amorphous-nanocrystalline structure can be strongly dependent on the conditions of the annealing procedure (*eg* on the number and average size of small iron rich nanoparticles).

3 EXPERIMENTS

Melt-spun amorphous $Fe_{75}Si_{15}Nb_3B_6Cu_1$ ribbons with thickness of 20mm, width of 10mm and length of 30mm were examined. The samples were wound from spooled, toroidal cores. The start-up cores were annealed under circulated hydrogen atmosphere in standard industrial furnace. The characteristic annealing temperature varied between 673 and 873 K. The duration of the annealing at a given temperature was 1 hour. Magnetic properties (permeability μ, coercivty H_C, loss angle δ were measured by commonly used industrial setup. Toroidal samples were excited by $I(t)=I_0\cos(\omega t)$ current and the hysteresis curve was evaluated from the U(t) potential measured in the secondary coil. LECROY LT 342 unit was used to measure the current and potential. Permeability and loss angle were measured by WK PMA 3260A equipment. Definition of these technical quantities can be found in [15, 16].

VT404 climate box and a special home-made micro press were used to investigate the temperature and mechanical sensitivity of the above finemet cores during temperature change and mechanical stress. In order to measure the mechanical sensitivities, the samples were deformed parallel to the diameter, *d*, and the change of permeability, $\Delta\mu_{norm}$, was measured. The details can be read in [10].

MBN of the samples was measured by the set-up schematically shown on Fig 2. Pick-up coil of 100, later 400 wounds was created. The exciting, 70 cm in length, solenoid was longer than the sample providing homogeneous field. Triangular exciting signal was used, ie the magnetization of the sample was linear with time. The zero symmetric, slowly changing exciting field could provide linear magnetization. The usual rate of change of the magnetic field was 50 A/(ms). The samples were magnetized under the excitation from negative to positive saturated state. The noise impulses (voltage signs), generated in the detector coil, enter the measuring card in the computer through several amplifier grades. The induced positive or negative voltages, generated by domain movements, depend on the direction of outer magnetic field. The tests were carried out on samples of 100×10×0.02 mm in size. Figure 1 shows the schema of sample holder and detector coil. The measured signals then were amplified with a usual amplifier chain and digitalized by an NI PCI MIO 16E-1 digital acquisition card with 12bit ADC. The sampling frequency was 1 MHz. The experimental distribution was created by a Labview based program. The measuring software processes the signs in real time, stores the spectra of amplitude, width, area and energy.

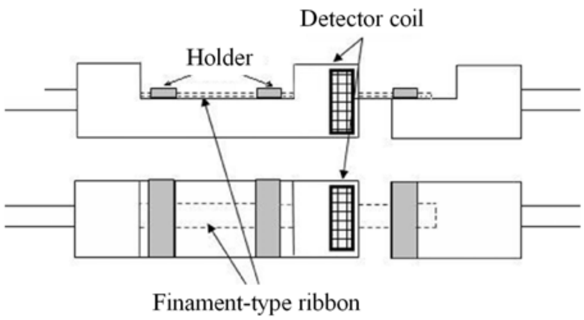


Fig. 1. Sample holder and the detector coil

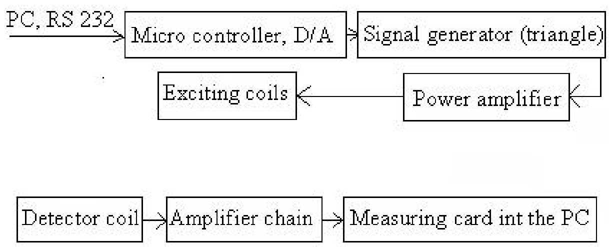


Fig. 2. Amplifier chain for processing the signs from the detector coils

It is very important to avoid the disturbing effect of outer noises, or at any rate to reduce to the minimal level. Peak detection level was introduced, *ie* only peaks, higher than this voltage value were detected. The distributions of peak area *A* and peak energy *E* were calculated

$$A=\int u(t)dt\,, \tag{1}$$

where $u(t)$ and t are the apparent voltage and the time and the integral runs from the start to the end of a peak) as well as

$$E=\int u^2(t)dt \tag{2}$$

The probability frequency curve of a certain property $P(x)$ satisfies the following function

$$P(x)=P_0x^{-\alpha}\exp(x/x_0)\,, \tag{3}$$

where α and x_0 are the scale exponent and cut off value respectively, x is the certain investigated property (duration, peak-height, integral or energy of the peaks).

The effect of the maximum annealing temperature on the properties of FINEMET type ribbons was investigated. Mechanical sensitivity was measured according to Fig. 1. From the analysis of the Barkhausen noise signals it was found that, both the scale exponents

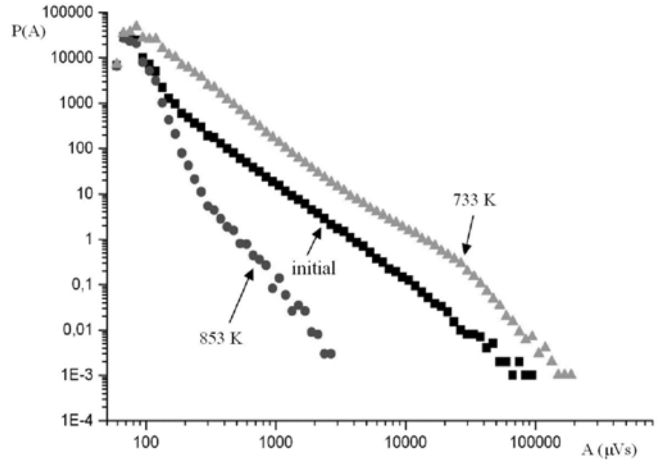


Fig. 3. Frequency distribution of area for the two extreme and initial cases

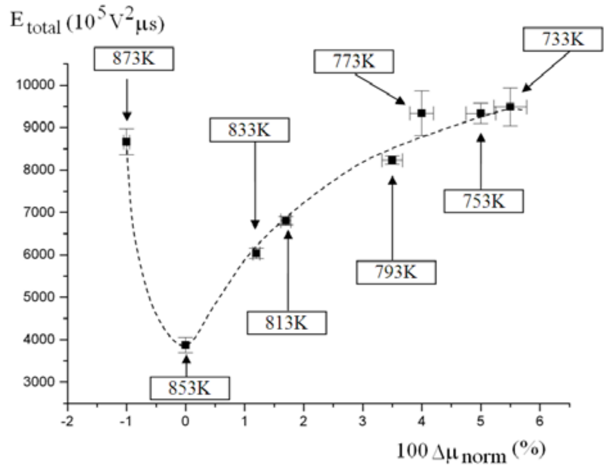


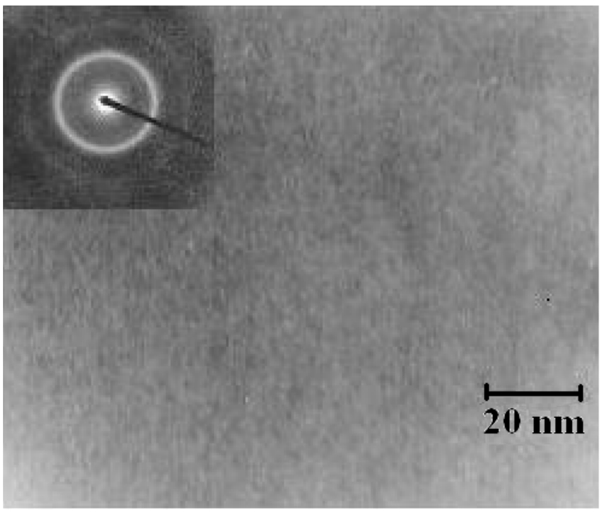
Fig. 4. Dissipated energy in the full magnetization cycles versus mechanical stress

and noise levels have been changed. During heat treatments, ie with gradual increase of the volume fraction of nanocrystalline Fe precipitated from the originally fully amorphous matrix (see [8] and [9]) the noise level (*ie* $P(A)$ at a certain value of the area A see Fig. 3, for $A = 1000$) increased from its as received (amorphous) value up to 733 K, than it decreased rapidly while the temperature further increased to 853 K, and suddenly increased again above 853 K [10].

Figure 3 shows the $P(A)$ functions for the two extreme cases (*ie* for samples annealed at 853 K and 733 K, respectively) as well as for the initial, fully amorphous sample.

Figure 4 shows the full dissipated energy E_{total} (calculated as the integral of the area below the $P(E)$ versus E functions) again versus mechanical sensitivity. This correlation between the value of noise and mechanical sensitivity can be very important in the determination of the optimum state of end products and also in the improvement of the quality control. It can be seen in Fig. 4 that the noise level has a definite minimum at 853 K, where the mechanical sensitivity is the smallest.

There were other investigations (see *eg* [8,11] to understand the extremely soft properties finemet type materials, especially by transmission electron microscope and Kerr-microscope. The electron microscopy is able to detect the state of samples after the different annealing phase (see Fig. 5).



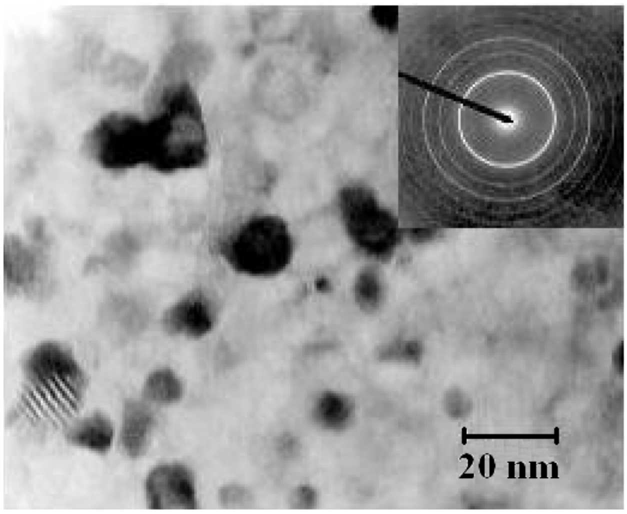


Fig. 5. Transmission electronic pictures of the amorphous and heated (up to 853 K) samples

4 CONCLUSIONS

Our experimental set up for the investigation of magnetic noise properties of Finemet type is described. Definite correlation between the mechanical sensitivity and the noise level of peak area, or the total dissipated energy, in annealed products is illsutrated. It is shown that minimal mechanical sensitivity corresponds to a very low magnetic Barkhausen noise. This fact can be used for diagnostic applications in industrial preparation of Finemet-type or other ferromagnetic materials.

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