FRACTAL DIMENSION ANALYSIS OF THE BARKHAUSEN NOISE IN Fe-Si AND PERMALLOY

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Abstract. – Nonlinear response of the magnetization respect to slowly changing magnetic field gives random noise, i.e., the Barkhausen noise, which is measured on Fe-Si and permalloy. Analysis of the experimental data shows that the Barkhausen noise has a fractal structure of low dimension between 0.7 and 1.3.

1. Introduction

Motion of domain walls in ferromagnetic materials is one of the interesting subjects in nonlinear dynamics. Since movement of walls is impeded by lattice imperfections, magnetization process under slowly varying magnetic field exhibits sequence of random jumps which produce well-known Barkhausen noise. Chaotic behavior [1-4] and self-similarity in the motion of a domain wall [5] have been discussed by many researchers. Characteristics of chaos and strange attractor in magnon system have been extensively studied [6, 7].

We have applied the fractal analysis to the Barkhausen noise because the sequence of random steps of the magnetization has a certain resemblance to the devil's staircase. Fractal dimensions of the Barkhausen noise observed in Fe-Si and permalloy are determined.

2. Specimens and experimental procedure

The experiments were carried out on polycrystalline specimen both of Fe-Si and permalloy. In order to perform magnetic measurements, we use frame-type specimen of Fe-Si which have a silicon content of 6.2 at. % . Sample dimensions are as follows; outer and inner dimensions are 15×15 mm^2 and 9×9 mm^2, respectively and 0.11 mm thick. The primary and secondary coils are wound around the four legs. For permalloy, cylindrical specimens, which have nickel content of 58.9, 79.1 and 94.1 at. % , are used. The dimensions are 120 mm in length and 0.7 mm in diameter. The primary coil for this sample are wound on the secondary coil.

When the magnetic field applied to the specimen is changed in a uniform fashion, the Barkhausen noise is detected as induced voltage arisen from the discontinuous changes of magnetization to a secondary coil and recorded with a digital signal analyser connected to a computer. Measurements are made at various sweep rate of magnetic field from 0.87 Oe/s to 57.1 Oe/s for Fe-Si and from 1.47 Oe/s to 96.9 Oe/s for permalloy. An example of the data is shown in figure 1 which is taken for permalloy of nickel content of 79.1 at. % .

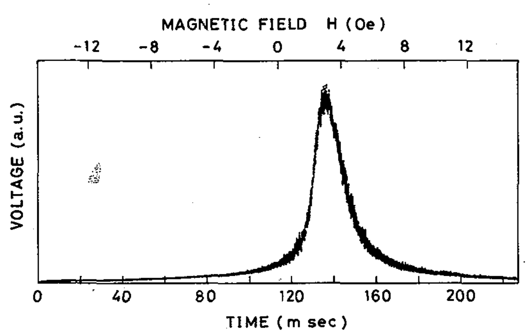

Fig. 1. – Barkhausen noise of permalloy (Ni:79.1 at. %).

3. Procedure of analysis

By integrating the signal a nonlinear magnetization curve is obtained as a function of magnetic field. Magnetization increments m during every 1 mOe increments of magnetic field are derived. The increment m, therefore, corresponds to average gradient between an interval of 1 mOe. Average gradient data could eliminate the noise generated by the experimental equipments from the original derivative data. The data of magnetization increment are examined by a standard scaling method [8] where the data are scaled by the magnitude of m. The cumulative number $N(m)$ of data which have larger value than a given m is obtained. The cumulative number $N(m)$ decreases monotonously with increasing m because the occurrence of larger jumps of the magnetization is less than that of the smaller ones. The dimensionality is given by the slope of $\ln\ [N(m)]$ *vs.* $\ln\ (m)$ in a certain range of values of m, if the plots of data have a linear relation. Here m is normalized by the maximum value of the magnetization in the measurements.

4. Results and discussion

Plots of ln $[N(m)]$ *vs.* ln (m) are shown in figures 2 and 3 for Fe-Si and permalloy, respectively. Both of them have enough linear regions to be able to define the fractal dimensions. The fact that $N(m)$ has the same exponent with widely different magnitude of m indicates these noise has characteristics of self-similarity, i.e., fractal. As shown in figure 4, the fractal dimension of Fe-Si depends on temperature and sweep rate of the magnetic field. With increasing sweep rate of the magnetic field, the fractal dimension decreases and approaches the constant values 1.02 and 1.30 at 290 and 77 K, respectively. That on permalloy, on the other hand, is independent of temperature. The fractal dimension in permalloy becomes large at 290 K as nickel content increases. The fractal dimensions in permalloy for nickel contents of 58.9, 79.1 and 94.1 at. % are 0.72, 0.80 and 1.32, respectively. The results at 77 K are 0.75, 0.79 and 1.30 for each nickel content, respectively.

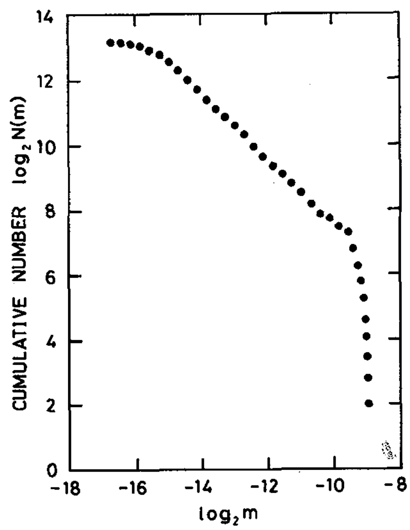

Fig. 2. – Cumulative number of data $N(m)$ as a function of magnetization increment m for Fe-Si at room temperature with sweep rate 39.1 Oe/s. Fractal dimension is 1.02.

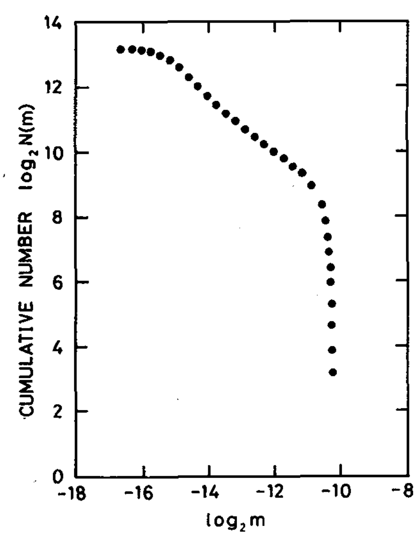

Fig. 3. – Cumulative number of data $N(m)$ as a function of m for permalloy of nickel content of 79.1 at. % at room temperature with sweep rate 66.3 Oe/s.

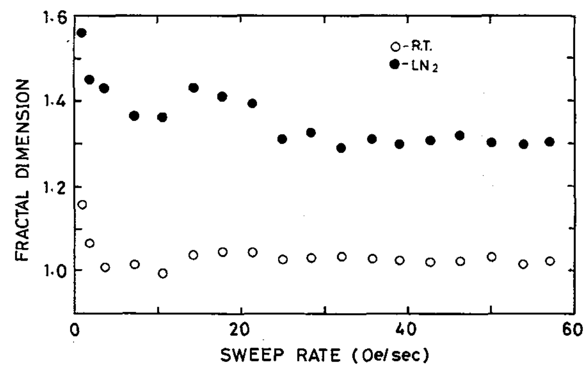

Fig. 4. – Fractal dimension of Fe-Si as a function of sweep rate at 290 and 77 K.

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