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Observation of interaction fields in the assembly of single domain particles

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ABSTRACT

A simple method is proposed for the observation of interaction in the assembly of single domain particles based on registration of anhysteretic remanent magnetization. In contrast to established methods relied on isothermal magnetization, the proposed method is more sensitive to the weak interaction and helps to find the distribution of the particles in the interaction fields. The method is very simple: a differentiating of a single experimental curve is enough to obtain the distribution. Verification of the method was performed on the samples of different origins and proved a good correlation of experimental results and numerical estimations.

1. Introduction

Magnetostatic interaction plays an essential role in the formation of properties of granular ferromagnet. That is why much theoretical research has been devoted to investigate this phenomenon [1–3]. The results of those studies conducted were a distribution of functions of random interaction fields and mean fields for some simple models. Real systems are complicated by many factors (agglomeration of particles, formation of clusters with high density, superparamagnetic environment, etc.), which could not be accounted for in the theoretical models. In addition, the experimental methods of registration of these parameters were not developed properly. The Wohlfart relations principle is the foundation of most experimental approaches of investigation of magnetostatic interaction in the assembly of stable single domain particles [4]. Interaction characteristics are obtained from analyzing curves of isothermal remanent magnetization measured at different initial states [5,6] or their derivatives (coercive force spectrum).

A method of FORC diagram [7,8] has been widely applied in recent years. The method is based on the analysis of isothermal remanent magnetization obtained through the processing of multiple minor hysteresis loops. This method gives much more information concerning the character of interaction in the assembly of single domain particles because it involves numerous initial states. However, the interpretation of an FORC diagram seems to us a very complex and ambiguous process, complicated by the time intensive procedure of diagram acquisition. The common feature of all known methods of experimental investigation of interaction in the assembly of single domain particles is the low sensitivity to the weak interaction. It makes it difficult to apply the methods to rock specimens or to amorphous alloys at the beginning of crystallization.

This prompted us to seek a method that is suitable for investigating weak interaction assemblies that can supplement the known experimental methods.

2. The foundation of the method

In our opinion, among other kinds of remanence, the anhysteretic remanent magnetization $M_{ri}(h,H)$ is most suited to the problem. The anhysteretic remanent magnetization (ARM) is obtained by applying a direct field H and at the same time an alternating field h which decreases to zero. Our method of the experimental determination of the distribution of the particles in the interaction fields is based on specificity of an ARM process. For the purposes of this argument, let us use the established model and the Preisach diagram (PD). According to this model, the formation of the remanent magnetization is a consequence of the irreversible switching of fictitious particles (a real particle for single domain samples) having asymmetric rectangular hysteresis cycles with critical fields a and $-b$ at which the particles are switched in positive and negative directions. Each such particle corresponds to the representative point on the PD. In the case of no interaction, all cycles are symmetric (excluding a rare case of unidirectional anisotropy); critical fields are equal to the coercive force of isolated particles ($a=-b=H_0$) and all points are on the bisector of the fourth quadrant corresponding to the irreversible switch. The presence of magnetostatic interaction leads to the displacement of reversal magnetization cycles by the value of interaction field and moving representative points in the direction perpendicular to the bisector. The distribution of these representative points or particles on the interaction fields can be obtained

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by an anhysteretic magnetization of the sample that is reflected in PD as an ac demagnetization (bringing to zero state) in a shifted coordinate system. Following the removal of direct field H and returning to the initial coordinates, all particles in the range of the interaction field from 0 to $-H$ become magnetized in a positive direction. In the PD, the particles will be found in a $2H$ wide strip close to the bisector. In the common case, $M_{ri}(h,H)$ is a function of the direct field H and maximum amplitude of alternating field h, but if H is higher than saturation field, then $M_{ri}(h,H)$ depends only from the direct field H. If we acquire $M_{ri}(H)$ and differentiate it on H, we obtain a cross section of magnetic density in PD. By introducing a term *cross section*, we would like to emphasize that the dependence characterizes a distribution of magnetic density in the direction perpendicular to the bisector of PD. It is evident that the cross section coincides with the density of particles distribution in the interaction fields. Based on the interpretation of M_{ri} in PD, it is obvious that

$$\frac{dM_{ri}}{dH} = 2m\frac{dN}{dH}\frac{1}{V} \quad (1)$$

where m—magnetic moment of a single particle, V—volume of the sample, dN—quantity of the particles in the interaction field from H to $H+dH$ and consequently dN/dH is the density of particles distribution in the interaction fields. Since $M_{ri}(H)$ does not depend on the distribution of particles in coercive fields and is fully defined by the distribution of the degree of asymmetry of hysteresis loops, this presents the best approach to the investigation of magnetostatic interaction in a single-domain assembly.

In the case of multi-phase samples that have some clearly evident maximums of coercive spectrum, it is possible to trace the separated cross sections for each phase. For this purpose, the direct field is applied only in the range of the magnitude changing of alternating field, corresponding to the selected phase.

Previous reasoning and plots in PD are correct only for the statistical stability of interaction field distribution, therefore the stability of the diagram i.e. when the magnetic density distribution is independent on magnetic state of a sample, though individual fields of particles are changing at any variation of the state. An increasing concentration followed by the rising of local field of interaction leads to the destruction of the stability. It is appropriate to consider peculiarities and usability conditions of the proposed method along with an isothermal magnetization reversal based methods. A strict construction of magnetization reversal of non-stable Preisach model is tedious [9–12] and may take us off direction from the assigned task, so let us confine ourselves to some qualitative reasoning. We will provide an analysis of three separate cases corresponding to the different relations of coercive fields of particles and interaction fields.

a. A concentration is so small that the occupied range in PD is a narrow strip symmetric with respect to bisector of the fourth quadrant (Fig. 1(a)). The width of the strip is defined by the local interaction fields. The mean field that is proportional to the magnetization [6] is so small that the location of the occupied area does not depend upon the magnetic state of the sample. A switching area in the constant field H at an initial

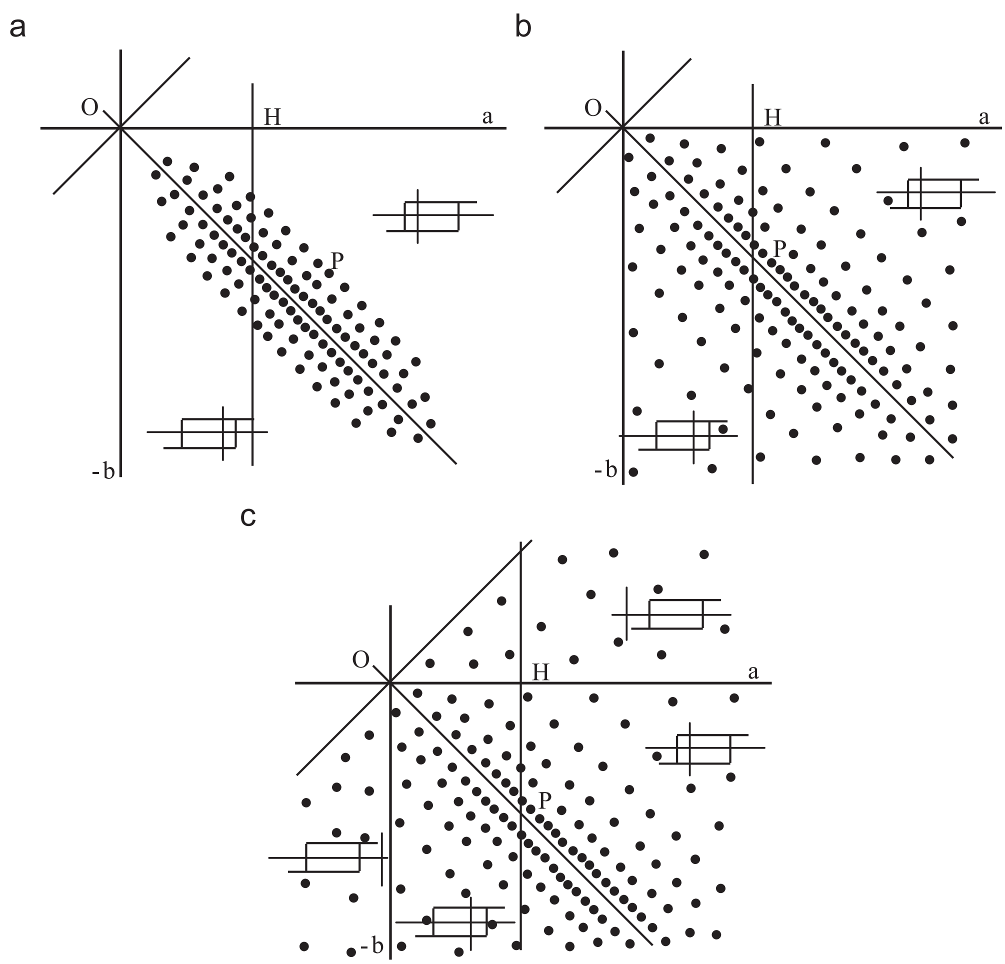

Fig. 1. Schematic illustration of different relations of coercive fields of particles and interaction fields in case of weak interaction (a), intermediate state (b) and strong interaction (c).