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# PREISACH MODEL, FIRST – ORDER REVERSAL CURVES

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Preisach model has been used extensively since the model has been initially developed by Ferenc Preisach about 75 years ago, especially for ferromagnetic materials. When the model has been analyzed from a mathematical point of view by Krasnoselskii and Pokrovskii and after them by Mayergoys and other scientists it was stated that, in fact, the model is "the best hysteresis model at our disposal" (A. Visintin, 1994) to describe any type of hysteretic process. The proven sound mathematical basis gives the model a privileged place among the many hysteresis models available in the scientific literature.

Within the scientific community there is a strong debate concerning the relation between the physical properties of the system and the (Preisach-type) model's parameters. Some authors argue that the Preisach model is phenomenological in essence (or purely mathematical) which it gives a wide range of applications but offers no possibility to find parameters with physical significance. In this case the model is used as a complex tool to approximate a broad range of experimental data with a limited set of parameters. However, we have to remark that most of the hysteresis models are originated in the effort to explain some concrete physical facts, observed on specific samples, and the building blocks of these models are based on these realities, expressed in a simplified manner in the mathematical formulation of the model. For example, the Classical Preisach Model (CPM) is usually seen as a tool to describe the scalar static magnetization processes in a system of interacting magnetic entities (single domain particles). The effect of interactions is an asymmetry of the rectangular hysteresis loop. In the CPM one assumes that the constitutive entities (named hysterons) are completely characterized by the switching fields that are distributed. Instead of the positive $(H_\alpha)$ and negative $(H_\beta)$ switching field distributions one uses the distributions of coercive fields $H_c = \left(H_\alpha - H_\beta\right)/2$ and interaction fields $H_i = -\left(H_\alpha + H_\beta\right)/2$. These two distributions are considered stable (do not change their shape during any magnetization process) and statistically independent. As a consequence, the irreversible Preisach distribution is the product between the two distributions:

$$p_{irr}\left(H_\alpha, H_\beta\right) = S p_{ii}\left(h_i\right) p_{ic}\left(h_c\right) \tag{1}$$

where $p_{ii}\left(h_i\right)$ is the Interaction Field Distribution (IFD), $p_{ic}\left(h_c\right)$ is the distribution of coercive fields and $S$ is the squareness. The distributions are normalized at the saturation magnetic moment of the sample. We have used a system of axes denoted with $\left(h_c, h_i\right)$ and rotated with 45° with respect to the $\left(H_\alpha, H_\beta\right)$coordinate system ($h_c = \sqrt{2}H_c$ and $h_i = \sqrt{2}H_i$) (see Fig. 1).

Mayergoyz have shown that the necessary and sufficient conditions that should be obeyed by a system to be correctly described by a CPM (CPM systems) are the wiping-out and congruency properties. However, many attempts to find magnetic CPM systems failed. Most of the known magnetic systems do not obey to the congruency property. As a consequence, the CPM has been repeatedly modified in order to provide a modeling solution for the systems showing wiping-out and non-congruency. These “Preisach-type” models, have the origin in the CPM but includes supplementary elements that provide a relaxation of the congruency property. One mention here the well known Moving Preisach Model (MPM) that adds to the statistical interaction field a mean interaction field and the Variable Variance Preisach Model (VVPM) that takes into account the change of the interaction field distribution variance as a function of the magnetic state of the sample..

Micromagnetic simulations made on systems of interacting single domain particles have shown that the mean interaction field and the variable variance are observable in real systems. Moreover, we have shown that the two effects are in fact linked. An essential observation is that we use a model that takes into account the fundamental physical details of the system, even if the primary nature of model is phenomenological, the model’s parameters have a clear physical significance. If one uses a model that does not give attention to the physical reality of the system, even if some experimental data measured on the system are correctly fitted by the model, the significance of the parameters becomes difficult to establish.

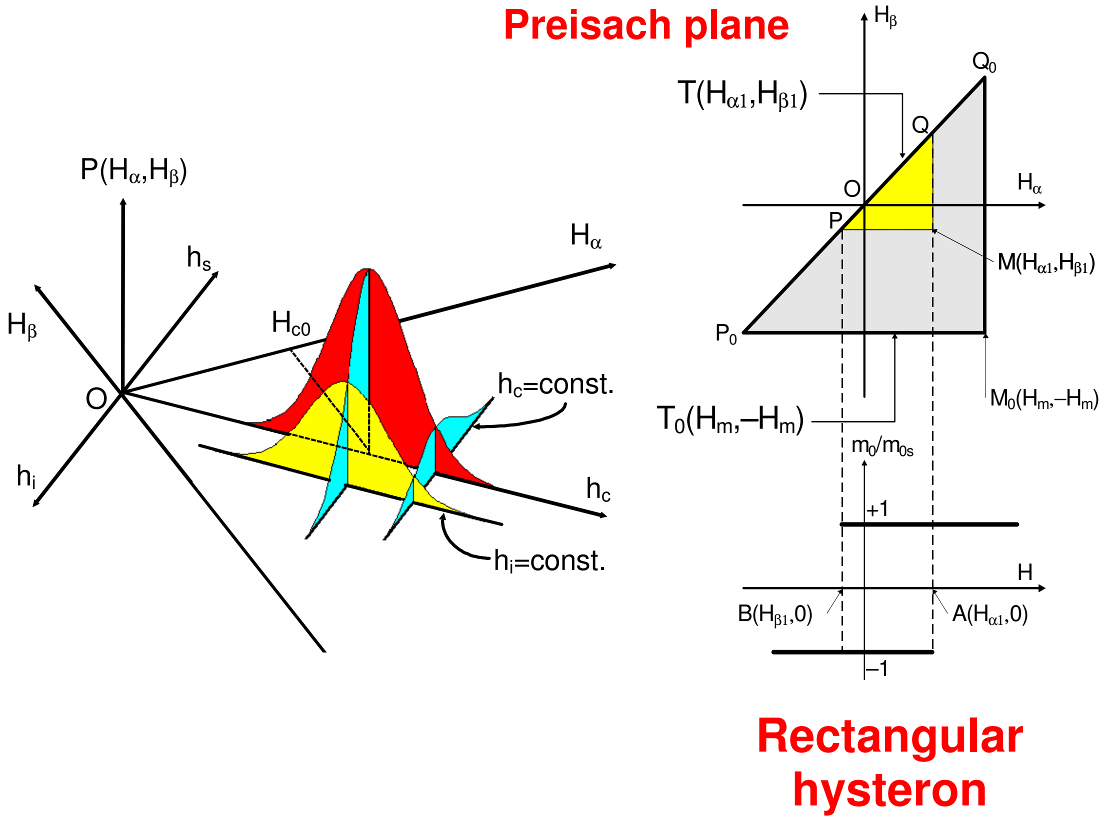

Fig. 1. Preisach plane and Preisach distribution of rectangular hysterons.

In this context, we have observed on micromagnetic simulations made on single domain particle systems that in many occasions (especially when the packing ration was high and particle clusters were observed in the system) the IFD in the DC demagnetized state had a clear two peaks shape. We also have seen that the two peaks shape can be decomposed in a sum of two Gaussian distributions with the amplitudes approximately proportional to the magnetic moment of the sample. At the positive saturation, one distribution has the maximum amplitude and the other one has zero amplitude and in the DC demagnetized state the amplitudes of the two distributions were equal. In the negative saturation the first distribution has zero amplitude and the second one has maximum amplitude. The dependence of the amplitude depends in many cases almost linearly with respect to the magnetic moment of the sample. We have developed a Preisach-type model (Preisach Model for Patterned Media = PM$^2$ model) that can use the bi-modal Preisach distribution and that contains as particular cases the MPM and VVPM models.

A problem of paramount importance is how we can evaluate the Preisach distribution and the supplementary parameters included in the modified versions of the model. Mayergoyz has designed an identification technique for the classical Preisach model based on a set of

First-order Reversal Curves (FORC) curves. As presented in Fig.2, these curves are obtained using a sequence of fields starting from a saturation state. If for simplicity one discuss only the FORCs originated on the descending branch of the Major Hysteresis Loop (MHL) we have to obtain initially the positive saturation followed by a field decrease down to a field named *reversal field* and then an increase during which the magnetic moment of the sample is measured. The magnetic moment on a FORC will depend consequently on two fields (actual field and reversal field) and the second order mixed derivative of the moment will give a value proportional to the Preisach distribution function.

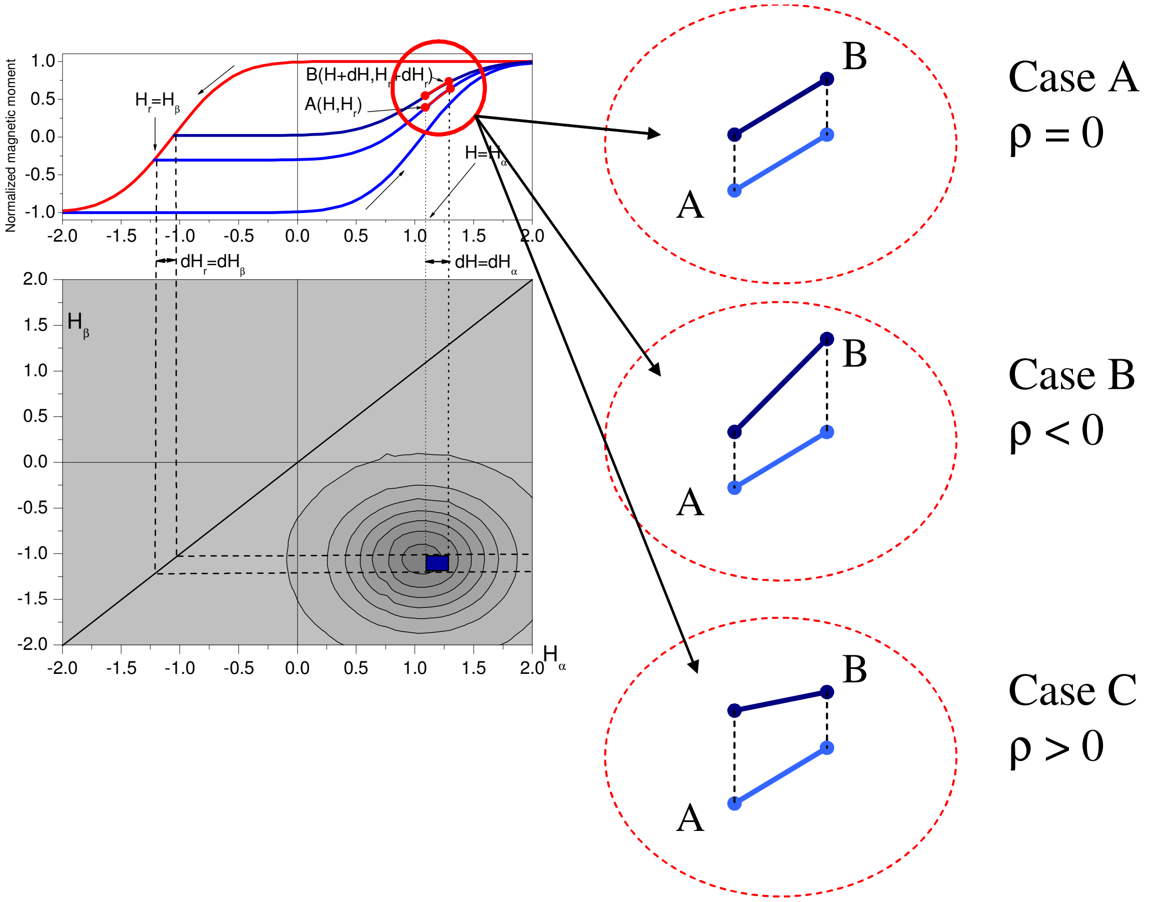

Fig. 2. FORC diagam (ρ = FORC distribution)

About a decade ago, Pike and collaborators from University of California Davis proposed the use of the method as a purely experimental tool to obtain a distribution (called FORC distribution) which is characteristic for the measured material. Even if the FORC distribution and the FORC diagram (the contour plot of the distribution) can be obtained rather easily in many laboratories, how to use properly these data is not an easy and straightforward process. Other models are required in order to understand the experimental diagrams obtained. In the lecture we shall present a multitude of aspects related to the proper use of the FORC diagrams in the characterization of magnetic materials.

We also shall show how this method can be extended to the study of another type of hysteretic process (thermal hysteresis in spin-transition materials) in order to emphasis method's generality.

We shall discuss various aspects of the problem, like the FORC diagram symmetry properties, mean field effects observed on the diagram, etc.

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