A REPRESENTATION OF MAGNETIC HYSTERESIS

Y. Saito, S. Hayano, T. Yamamura and N. Tsuya

College of Engineering, Hosei University
3-7-2 Kajinocho Koganei, Tokyo 184 Japan

Abstract - Preisach and Chua type models for magnetic hysteresis are studied with respect to their principal idear for modeling. This paper elucidates that both the Preisach and Chua type models can be derived from a common picture. Also, this paper proposes a specific model that can embrace essential parts of both Preisach and Chua type models.

INTRODUCTION

In order to represent the hysteretic properties of magnetization, Preisach has proposed a model which assumes that each of the domaines possesses a rectangular hysteresis loop and interaction between domaines can be introduced by assuming local fields acting on the domains [1]. Even though the Preisach type model is based on such simple assumptions, it gives valuable results that are in agreement with experimental results [2]. There is however an instability problem [3] for which the Preisach's function takes an different value depending on the previous path in the magnetization processes.

Chua and Stromsmoe have worked out a lumped circuit model for nonlinear inductors exhibiting hysteresis loops [4]. Furthermore, they have generalized their model to a static hysteresis model [5]. Their model is based on the fact that a trajectory of flux linkage vs. current is uniquely determined by the last point at which the time derivative of flux linkage changes sign. Their model exhibits many important hysteretic properties commonly observed in practice. However, their model is too complex to use the two- or three-dimensional magnetic field calculations.

Saito had proposed a specific model that is similar to the Chua type model for analyzing the three-dimensional magnetic field distributions in electromagnetic devices [6,7].

In this paper, we elucidate that both the Preisach and Chua type models can be derived from a common picture. We also propose a specific model that can embrace essential parts of both Preisach and Chua type models.

THE MAGNETIC HYSTERESIS MODEL

Chua Type Model

The specific model belonging to Chua assumes that

$$H = (1/\mu)B + (1/s)\partial B/\partial t, \tag{1}$$

where H, B, μ, s and t denote the field intensity, flux density, permeability, hysteresis coefficient and time, respectively [6,7].

From an experimental point of view, the magnetization is accomplished in essence through the time varying flux density. In (1), a magnetization hystory is implicit through the value of the peak flux density. The time derivative of the flux density $\partial B/\partial t$ takes an different signs on the ascending branch or descending branch of the hysteresis loop, and takes different values depending on the rate of change $\partial B/\partial t$. This means that a magnetization trajectory is uniquely determined by the sign of $\partial B/\partial t$ as well as the rate of change $\partial B/\partial t$.

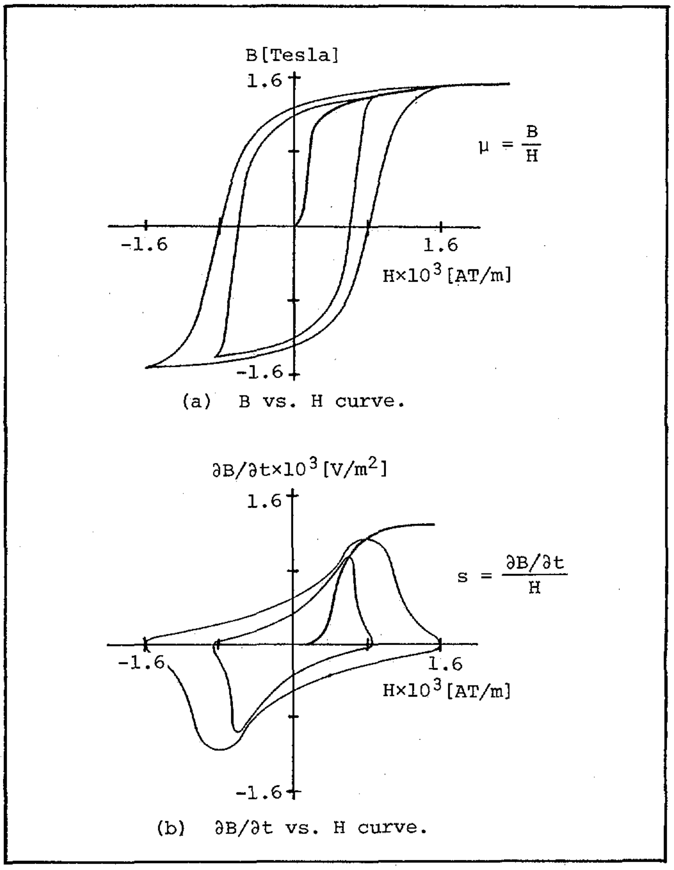

Fig. 1. Magnetization curves for (1).

Since the term $\partial B/\partial t$ in (1) becomes zero when the flux density B arrives at the positive or negative maximum value, a trace of the peak points on the B vs. H trajectories yields a single valued function of permeability μ shown in Fig. 1(a), where the hysteresis coefficient s becomes to quite small in value but not zero. Similarly, a trace of the peak points on the $\partial B/\partial t$ vs. H trajectories yields a single valued function of the hysteresis coefficient s shown in Fig. 1(b), because the flux density B becomes to zero when the time derivative of the flux density $\partial B/\partial t$ in (1) arrives at the positive or negative maximum value.

Preisach Type Model

According to the [2], the reversing point field intensity H_n and applied field intensity H_p are defined as shown in Fig. 2. By considering Fig. 2, it is obvious that the B vs. H trajectory takes different paths depending on the reversing point field intensity H_n. Thereby, the flux density B is represented as a function of the applied field intensity H_p as well as reversing point field intensity H_n,

$$B = B(H_p, H_n). \tag{2}$$

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Moreover, by considering a saturation point of flux density on the nonsymmetrical hysteresis loop shown in Fig. 2, it is revealed that the B vs. H trajectories takes different paths according to each of the reversing point of field intensities but always coincide at the saturation point of flux density. Therefore, the rate of change of slope $\partial B/\partial t$ with the reversing point field intensity H_n takes non-zero value in the region $|B|<B_m$, where B_m is the saturation flux density. This relationship gives the definition of Preisach's function Ψ as

$$\Psi = \partial^2 B(H_p,H_n)/\partial H_n \partial H_p. \quad (3)$$

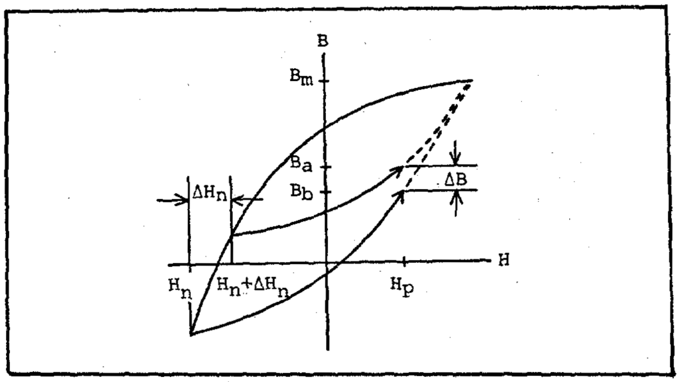


Fig. 2. Derivation of Preisach's function Ψ.

Comparison of Models

The Chua type model is based on the fact that the magnetization path is uniquely determined by $\partial B/\partial t$. On the other side, the Preisach type model is based on a behavior that the change of slope $\partial B/\partial H$ depends on the reversing point field intensities.

In order to find a relationship between them, application of (1) to the states of Fig. 2 gives the following relations:

$$H_p = (1/\mu)B_a + (1/s)\partial B_a/\partial t, \quad (4)$$

$$H_p = (1/\mu)B_b + (1/s)\partial B_b/\partial t, \quad (5)$$

where the field intensity ΔH_n in Fig. 2 is so small that the permeability μ and hysteresis coefficient s may be assumed to be constant. By subtracting (4) from (5) and rearranging, it is possible to obtain

$$\begin{aligned}\Delta B/\mu &= (1/\mu)(B_a - B_b)\\ &= (1/s)[(\partial B_b/\partial t) - (\partial B_a/\partial t)]\\ &= (1/s)[(\partial B_b/\partial H_p) - (\partial B_a/\partial H_p)]\partial H_p/\partial t.\end{aligned} \quad (6)$$

Further rearrangement of (6) yields

$$s/(\partial H_p/\partial t) = (\mu/\Delta B)[(\partial B_b/\partial H_p) - (\partial B_a/\partial H_p)]. \quad (7)$$

In Fig. 2, if the limit of ΔH_n goes to zero, then $\Delta B/\mu$ term in (7) is simultaneously reduced to zero. Thus an assumption of $\Delta H_n=\Delta B/\mu$ leads to

$$\begin{aligned}&\lim_{\Delta H_n \to 0} (\mu/\Delta B)[(\partial B_b/\partial H_p) - (\partial B_a/\partial H_p)]\\ &= \partial^2 B/\partial H_n \partial H_p.\end{aligned} \quad (8)$$

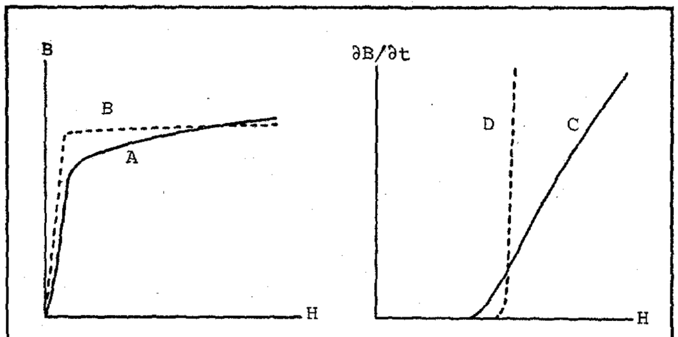
From (3),(7) and (8), a relationship between the hysteresis coefficient s and the Preisach's function Ψ is obtained as

$$s = \Psi(\partial H/\partial t). \quad (9)$$

MAGNETIZATION CHARACTERISTICS

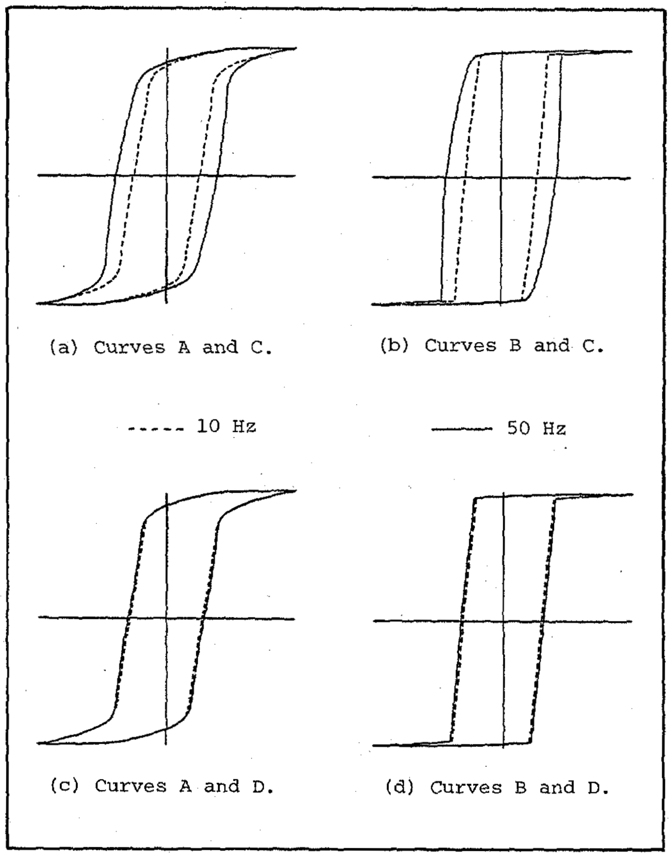
Classification

When the flux B in (1) is sinusoidally varying with time, the resulting hysteresis loops can be roughly classified into two kinds of shapes: the one is normal and the other is square in their shapes. Each of them is further classified into two-types according to the frequency dependence. Figs. 3(a) and 3(b) show the typical B vs. H curves for μ and $\partial B/\partial t$ vs. H curves for s in (1), respectively. Combination of these curves in (1) when the flux B is sinusoidally varied yields the four kinds of shapes of hysteresis loop shown in Fig. 4.



(a) B vs. H curves. (b) $\partial B/\partial t$ vs. H curves.

Fig. 3. Typical magnetization curves.



(a) Curves A and C. (b) Curves B and C.

(c) Curves A and D. (d) Curves B and D.

Fig. 4. Various hysteresis loops.

By considering the results of Fig. 4, it is obvious that the frequency dependence of hysteresis loop is dominated by the $\partial B/\partial t$ vs. H curves for hysteresis coefficient s. In other words, the hard magnetic materials have the curve D in Fig. 3(b) for hysteresis coefficient s, because their hysteresis loops hardly exhibit the frequency dependence, while the soft magnetic materials show the the curve C in Fig. 3(b), because their hysteresis loops strongly exhibit the frequency dependence.

An alternative classification of the hard and soft magnetic materials is made by means of the special distribution of Preisach's function Ψ in (9) [3,8].

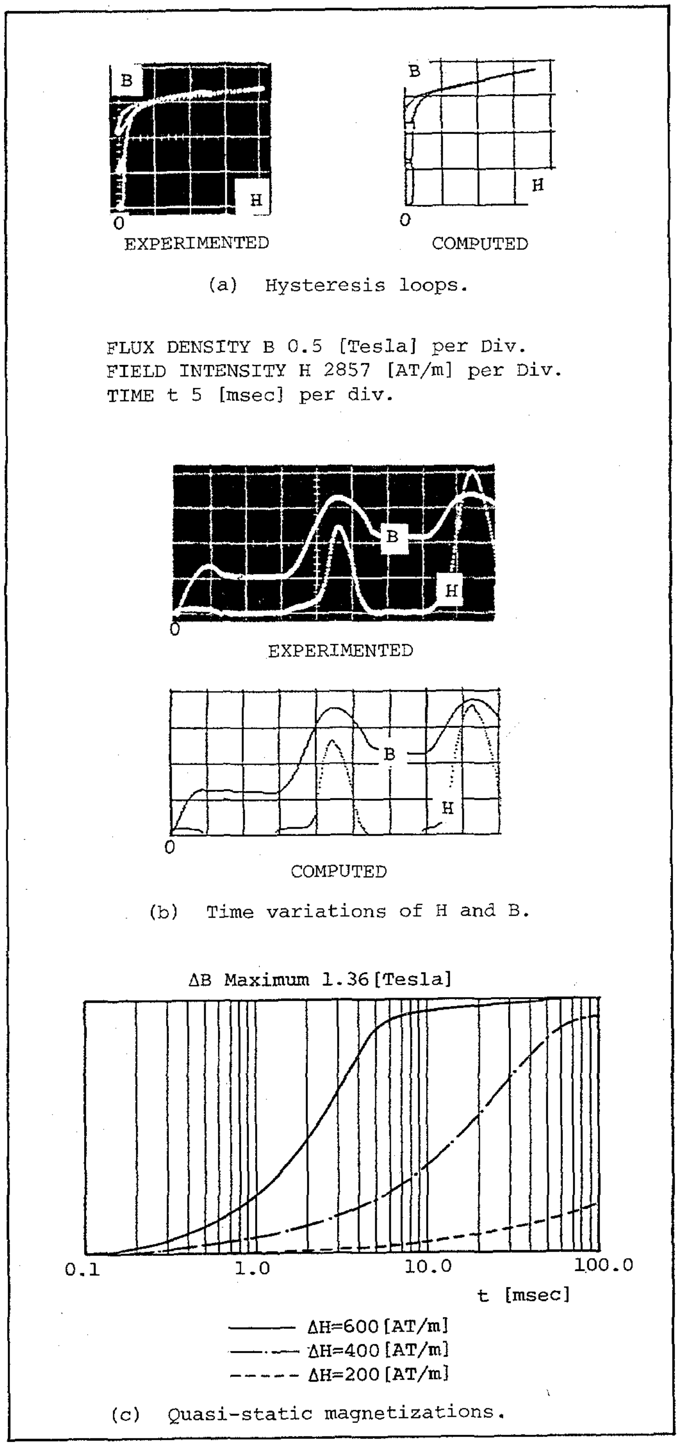


Fig. 5. Examples of quasi-static magnetization.

Quasi-Static Magnetization

It is of great interest to explain the remanent process by means of the present model. When $(1/s)\partial B/\partial t$ in (1) is negligible small, there is no remanence of B after the removal of magnetic field H. Whereas in the same process, when $(1/s)\partial B/\partial t$ is quite large, B is calculated by means of (1). Such B remains almost unchanged from its intial value even a long time after the removal of H and approximate value of remanence can be defined as shown in Figs. 5(a) and 5(b). Figs. 5(a) and 5(b) show respectively the hysteresis loops and time variations of H, B in the half wave rectifier circuit.

When the field intensity H in (1) is step-wisely changed from H to $H+\Delta H$, this is defined as the quasi-static magnetization. Fig. 5(c) shows the solution ΔB in (1) for various ΔH. These results are for the soft iron, and their μ and s are shown in Figs. 1(a) and 1(b).

According to the observation [9], the change of flux density ΔB in Fig. 5(c) is proportional to ln t. It is interesting to note that there is a region where ΔB is proportional to ln t in Fig. 5(c).

CONCLUSIONS

A relationship between the Preisach and Chau type models is given. A new model that is applicable to the soft magnetic materials as well as hard magnetic materials is proposed.

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