Construction of Magnetic Hysteresis Loops from the Normal BH Curve and Intrinsic Coercivity

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***Abstract*—This paper presents an algorithm to construct the major and symmetric minor hysteresis loops based on the normal magnetization curve and intrinsic coercivity, which are generally available from the manufacturers. The vertexes of the constructed hysteresis loops are all on the given normal magnetization curve, as the normal magnetization curve is defined. As an application of the proposed algorithm, some hysteresis loops are constructed from the measured magnetization curve and compared with the measured ones.**

***Index Terms*—Coercive force, magnetic hysteresis.**

I. Introduction

Parameter identification for various Preisach models requires a lot of first order reversal curves [1], which are normally not available from the manufacturers. A lot of approaches have been published in the literatures to identify the required parameters from only the major loop, while minor loops are determined by estimation [2]-[4].

This paper presents a new algorithm to construct the major and symmetric minor hysteresis loops based on the normal magnetization curve and the intrinsic coercivity (coercive force), which are generally available from the manufacturers. The vertexes of the constructed major and minor hysteresis loops are all on the given normal magnetization curve, as the normal magnetization curve is defined. The constructed hysteresis loops can be used for parameter identification for various hysteresis models, and also for the determination of the demagnetization curves in a magnetization simulation. As an application of the proposed algorithm, hysteresis loops are constructed from the measured magnetization curve and compared with the measured ones.

II. Construction of the Major Loop

The major hysteresis loop consists of an ascending branch $M_{asd}(h)$ and a descending branch $M_{dec}(h)$. The ascending, or descending, branch can be directly obtained from each other based on the odd symmetry condition, and therefore, only one branch, such as the ascending branch, is required to be constructed.

The ascending branch can be expressed as

$$m = M_{asd}(h) \tag{1}$$

which can also be expressed by compound functions as

$$m = M_{an}(h_{re}) = M_{an}(H_{re}(h)) \tag{2}$$

where $M_{an}(h_{re})$ and $H_{re}(h)$ are two functions to be determined. This paper presents a decoupled algorithm to derive $M_{an}(h_{re})$ from only the normal magnetization curve, and determine $H_{re}(h)$ from the intrinsic coercivity of the major loop.

A. Determination of the $M_{an}(h_{re})$ Curve

A normal magnetization curve is shown by the <u>*OTS*</u> solid curve in Fig. 1, in which a tangential line is drawn at point T where dm/dh has the maximum value. If the intercept of the tangential line at point C is denoted as h_{cim}, and the curve defined by <u>*CTS*</u> is expressed as $H_{asm}(m)$, then one obtains the $M_{an}(h_{re})$ curve by linearly mapping point C to O while keeping point S unchanged, shown by the long dashed line in Fig. 1, as

$$\begin{cases} H_{an}(m) = H_{asm}(m) - \Delta h \\ M_{an}(h_{re}) = H_{an}^{-1}(h_{re}) \end{cases} \tag{3}$$

where $H_{an}^{-1}(h_{re})$ is the inverse function of $H_{an}(m)$, and

$$\Delta h = h_{cim} \cdot (h_s - h)/(h_s - h_{cim}). \tag{4}$$

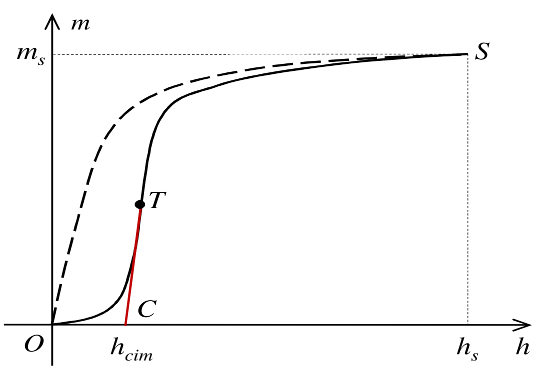

Fig. 1. Determination of the $M_{an}(h_{re})$ Curve

B. Determination of the $H_{re}(h)$ Curve

The value h of the $M_{an}(h)$ is defined as h_{re}, therefore, the long dashed curve in Fig. 1 is mapped to a line through points O and S if it is drawn in the h_{re}-h plane, and the <u>*CTS*</u> curve in Fig. 1 is mapped to a line through points C and S, as shown in Fig. 2.

In Fig. 2, for any given intrinsic coercivity of the major loop $h_{ci} \geq h_{cim}$, one can create a smooth curve through the following three points to construct the ascending branch in the h_{re}-h plane: $Q(-h_s, -h_s)$, $P(h_{ci}, 0)$, and $S(h_s, h_s)$. A smooth curve with continuous first derivatives can be obtained from

$$H_{re}(h) = \begin{cases} k_1(h-h_{ci}) + \dfrac{1}{2}\cdot\dfrac{k_2-k_1}{h_s-h_{ci}}(h-h_{ci})^2 & \text{if } h \geq h_{ci} \\ -h_s + k_0(h+h_s) + \dfrac{1}{2}\dfrac{k_1-k_0}{h_{ci}+h_s}(h+h_s)^2 & \text{if } h < h_{ci} \end{cases} \tag{5}$$

where k_0, k_1, and k_2, to be determined parameters, are the values of dh_{re}/dh at points Q, P, and S, respectively, and are constrained by

$$\begin{cases} k_0 = 2h_s/(h_s + h_{ci}) - k_1 \\ k_2 = 2h_s/(h_s - h_{ci}) - k_1 \end{cases} . \tag{6}$$

For the proposed algorithm, k_1 is computed from

$$k_1 = \begin{cases} h_s/(h_s - h_{ci}) & \text{if } h_{ci} \le h_s/3 \\ 2h_s/(h_s + h_{ci}) & \text{if } h_{ci} > h_s/3 \end{cases} . \tag{7}$$

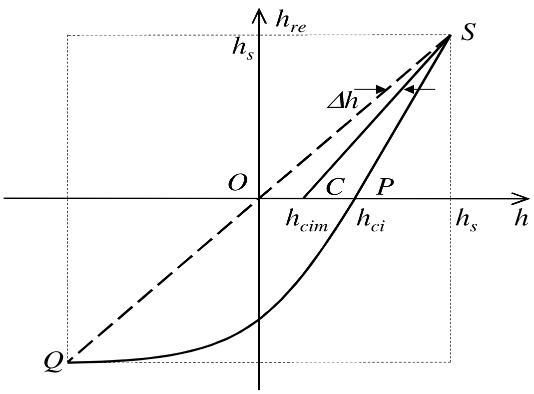

Fig. 2. Determination of the $H_{re}(h)$ Curve

III. Construction of Minor Loops

It is well known that a normal magnetization curve is obtained from the vertexes of a series of measured hysteresis loops with various field amplitudes, which provides useful information in minor loop construction. The magnetization curve in the m-h plane (see Fig. 1) is mapped to *OTS* curve in the h_{re}-h plane, as shown in Fig. 3. For a given vertex S′(h_s', h_{res}') of a minor loop, the intrinsic coercivity is estimated from

$$h_{ci}' = \begin{cases} h_{cim} + \dfrac{h_s' - h_t}{h_s - h_t}(h_{ci} - h_{cim}) & \text{if } h_s' \ge h_t \\ h_s' - \dfrac{h_s - h_s'}{h_s - h_{res}'} h_{res}' & \text{if } h_s' < h_t \end{cases} \tag{8}$$

where h_t is the h value at point T. Finally, the ascending branch for the minor loop in the h_{re}-h plane $H_{re}'(h)$ is obtained by creating a curve through the three given points Q′($-h_s'$, $-h_{res}'$), P′(h_{ci}', 0), and S′(h_s', h_{res}') based on the same algorithm as that for the major loop.

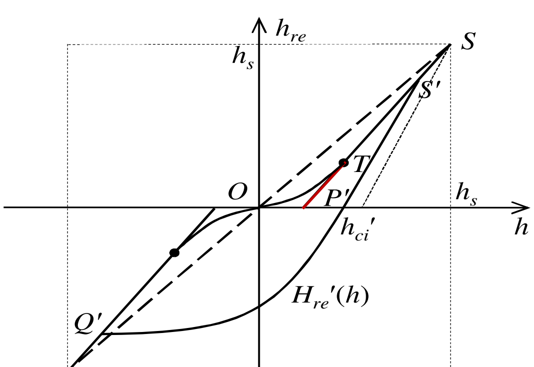

Fig. 3. The ascending branch of a minor loop in the h_{re}-h plane

IV. Applications

A measured normal BH curve and major hysteresis loop are cited from [5], and are shown in Fig. 4, where a constructed major loop based on the measured normal BH curve and the coercivity using the proposed algorithm is compared with the measured major loop. Another measured BH curve is cited from [6], and constructed major and minor hysteresis loops are shown in Fig. 5.

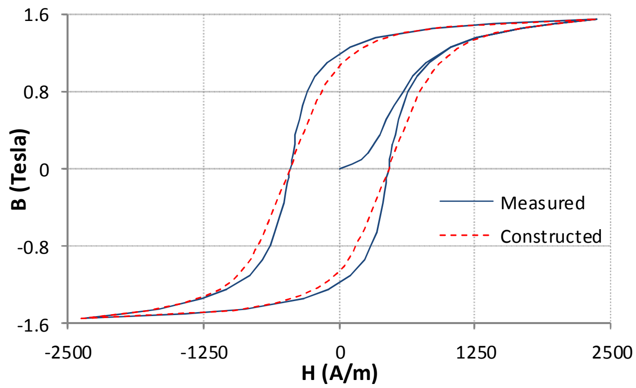

Fig. 4. Constructed major hysteresis loop compared with the measured one cited from [5]

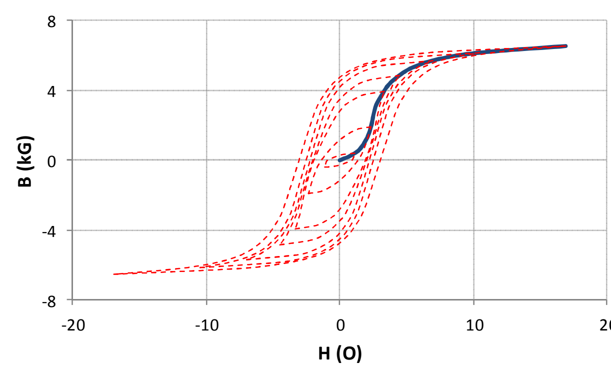

Fig. 5. Constructed major and minor hysteresis loops based on the measured normal BH curve cited from [6]

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