An Identification Method of Play Model With Input-Dependent Shape Function

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A product form of the input-dependent shape function is applied to the play model. This paper presents a method to determine the input-dependent shape function, thereby improving the representational accuracy of the play model. A simple data correction before identification is also introduced for the play model to avoid unnatural BH loops.

Index Terms—Hysteresis, identification, play model, silicon steel sheet, weighting function.

I. INTRODUCTION

The play model and the stop model [1], [2] are efficient hysteresis models that can be implemented more simply than the Preisach model [3], [4]. The play model with an input-independent shape function has been proven equivalent to the static scalar Preisach model [2], [5]. A previous study [6] has shown that the play and stop models with input-dependent shape functions are both equivalent to the nonlinear Preisach model proposed by May ergoyd [3]. May ergoyd proposed an identification method for the nonlinear Preisach model. This identification method uses second-order reversal curves of the hysteretic property. However, it is difficult to measure all second-order reversal curves that are required for identification.

On the other hand, a product form of the input-dependent shape function was proposed in [7] for the stop model. This form allows the stop model with input-dependent shape function to be identified using a two-step procedure: 1) determination of a weighting function; and 2) identification of the stop model with input-independent shape function.

This paper applies the product form of an input-dependent shape function to the play model and proposes an identification method of the play model with input-dependent shape function. This method determines the weighting function using the least-squares method.

II. PLAY MODEL WITH INPUT-DEPENDENT SHAPE FUNCTION

The play model usually obtains a hysteretic output of magnetic flux density $B$ from an input of magnetic field $H$. However, the play model can also provide an output $H$ from input $B$ in the same way as the Preisach model, using the inverse distribution function method [8].

A discretized form of the play model with input-dependent shape function describes a hysteretic function having input $B$ as

$$H = P(B) = \sum_{m=1}^{2M} f_m(p_{cm}(B), B)$$

(1)

$$p_{cm}(B) = \max \left( \min \left( \left( \frac{p_1}{B + \zeta} \right), B - \zeta \right) \right)$$

(2)

where $p_{cm}$ is the play hysteron operator having width $\zeta$, $2M$ is the number of hysterons, $\zeta_m = (m - 1)B_S/(2M)$, $p_1$ is the value of $p_{cm}$ at the previous time point, $f_m$ is the input-dependent shape function for $p_{cm}$, and $B_S$ is the saturation magnetic flux density.

A product form of the input-dependent shape function

$$f_m(p, B) = w(B)f_{m0}(p)$$

(3)

was proposed in [7] for the stop model, where $w(B)$ is called the weighting function. Using (3) for the play model (1), relation (4) is obtained as

$$P(B) = P_0(B) = \sum_{m=1}^{2M} f_{m0}(p_{cm}(B))$$

(4)

where $P_0(B)$ represents the play model having an input-independent shape function $f_{m0}$.

Identification of the play model using (3) requires determination of functions $w(B)$ and $f_{m0}$. This paper proposes a method for determination of $w(B)$ using a least-squares method after a discussion of identification of $f_{m0}$.

III. IDENTIFICATION OF PLAY MODEL WITH INPUT-DEPENDENT SHAPE FUNCTION

A. Identification Using the Everett Function

Because of its equivalence to the Preisach model, a play model with input-dependent shape function can be identified from the Everett function [4], [9] as follows.

The Everett function $E(\alpha, \beta)$ is defined from symmetric loops as

$$E(\alpha, \beta) = \left\{ \begin{array}{ll}
\frac{h_0^- (\beta, \alpha) - h_0^+ (\beta, \alpha)}{h_0^- (\alpha, \beta) - h_0^+ (\alpha, \beta)} & (\alpha + \beta \geq 0) \\
\frac{h_0^- (\alpha, \beta) - h_0^+ (\alpha, \beta)}{h_0^- (\beta, \alpha) - h_0^+ (\beta, \alpha)} & (\alpha + \beta \leq 0)
\end{array} \right.$$  

(5)

where $h_0^\pm (\alpha, B)$ and $h_0^\pm (\alpha, B)$ are, respectively, the ascending and descending branches of the symmetric loop with amplitude $\alpha$.

A piecewise linear shape function as (6) is used for identification

$$f_{m0}(p) = f_{m0}(p_{m,j-1}) + \mu_{m,j}(p - p_{m,j-1})/\Delta p$$

$$\left( p_{m,j-1} \leq p \leq p_{m,j}, j = 1, \ldots, 2M - m + 1. \right)$$

(6)

Therein, $p_{m,j} = -B_S + \zeta_m + j\Delta p$, $\Delta p = B_S/M$, and $\mu_{m,j} = f_{m0}(p_{m,j}) - f_{m0}(p_{m,j-1})$. The Everett function gives $\mu_{m,j}$ as

$$\mu_{m,j} = E(b_{j-1}, b_k) - E(b_{j-1}, b_{k-1}) = E(b_j, b_k) + E(b_j, b_{k-1})$$

(7)

$$k = m + j - 1$$

(8)
where $\alpha = n\Delta B, B_m = m\Delta B$ and $\Delta B = B_S/M$. This relation (10) yields a positive $\mu_{2m,M-m+1}$ as

$$
\mu_{2m,M-m+1} = 2\{h^+_{sM}(a_{m-1}, B_{m-1}) - h^-_{sM}(a_{m}, B_{m-1})\}
$$

where symmetric condition $h^+_{sM}(a, B) = -h^-_{sM}(a, -B)$ is assumed. Fig. 1(a) shows that $\mu_{40a}$ has a large positive value.

To prevent $\mu_{2m,M-m+1}$ from becoming positive, the values of $h^+_{sM}(a_{m-1}, B_{m-1})$ and $h^-_{sM}(a_{m-1}, -B_{m-1})$ are replaced by those of $h^+_{sM}(a_{m}, B_{m-1})$ and $h^-_{sM}(a_{m}, -B_{m-1})$, respectively, before identification. Fig. 1(b) depicts the distribution of $\mu_{m,j}$ after this data correction, where the large positive value of $\mu_{m,j}$ disappears. Fig. 2(b) shows BH loops given by identification after data correction, where BH loops are naturally represented.

**IV. IDENTIFICATION OF A PLAY MODEL WITH INPUT-DEPENDENT SHAPE FUNCTION**

**A. Determination of Weighting Function**

For a hysteretic function $H(B)$ to be represented accurately by the play model using (3), $H(B)/w(B)$ should have the congruency property as the Preisach model requires [2]. This property is used to determine an optimal $w(B)$.

First-order reversal curves from negative saturation give the Everett function [4] $E(\alpha, \beta)$ as

$$
E(\alpha, \beta) = h_R(\beta, \beta - h_R(\beta, \alpha)
$$

where $h_R(\alpha, B)$ is the first-order reversal curve having maximum input $a$. The congruency property requires that the Everett function given by (12) coincides with that of (3).

Accordingly, an optimal weighting function is given by a least-squares method that determines $v_i (n = 0, \ldots, M - 1)$ to minimize the following:

$$
\sum_{i=M+1}^{M+M} \sum_{m=0}^{M+M} [v_i (h^+_{sM}(a_{m}, B_{m}) - h_R(a_{m}, B_{m})))
$$

The last term in (13) is introduced to yield a nonzero solution. A piecewise linear weighting function is given from $v_i$ by

$$
u(B) = \frac{w_m + (w_{m+1} - w_m)(B - B_m)/\Delta B}{(B_m \leq B \leq B_{m+1})}
$$

$$
u_m = 1/\eta_m(m = -M + 1, \ldots, M - 1)
$$

$$
u_{\pm M} = 2w_{\pm(M-1)} - w_{\pm(M-2)}.
$$

**B. Numerical Examination**

Identification from symmetric BH loops gives a highly accurate representation of symmetric BH loops, as shown in Fig. 2(b). Accordingly, this subsection compares simulated and measured first-order reversal curves from negative saturation.
Fig. 3. Simulated first-order reversal curves and average representation errors given by the play model with weighting function 1).

Fig. 4. Simulated first-order reversal curves and average representation errors given by the play model with weighting function 2).

Fig. 5. Simulated first-order reversal curves and average representation errors given by the play model with weighting function 3).

V. CONCLUSION

- This paper introduced a simple data correction before identification of the play model; it prevents the play model from yielding unnatural BH loops.
- A method for determining the weighting function was proposed. The method improves the play model’s representation accuracy.
- A simple weighting function using a major loop width is also effective, as in the case of the stop model.

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REFERENCES


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