

# Improved Vector Play Model and Parameter Identification for Magnetic Hysteresis Materials

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**Abstract**—An improved vector play model for magnetic hysteresis materials is proposed, and its required parameters are identified from input major hysteresis loop. Validation results show that this new vector hysteresis model improves the accuracy of core loss computation not only for rotating fields, but also for alternating fields compared with the ordinary vector play models. The presented model has been successfully implemented in 2-dimensional (2D) and 3-dimensional (3D) transient finite element analysis (FEA). Some application results from the 2D and 3D transient FEAs are presented.

**Index Terms**—Magnetic hysteresis, modeling.

## I. INTRODUCTION

To predict the magnetization behavior for isotropic magnetic materials with hysteresis in 2-dimensional (2D) or 3-dimensional (3D) transient finite element analysis (FEA), it has been realized that the vector play model [1]-[4] is more computationally efficient than various vector Preisach models [5]-[7]. However, the ordinary vector play model does not obey the rotational loss property that the magnetic hysteresis loss of any applied rotating magnetic field tends to become zero when the magnitude of the applied rotating magnetic field becomes saturated, but not the infinity [5], [8]-[9]. Some modified vector play models have been developed to satisfy the loss property [1]-[2]. However, their applications are limited in practice due to the difficulty in parameter identification.

This paper presents a vector hysteresis model using improved vector play operator to predict the magnetization behavior for isotropic magnetic materials with hysteresis. All required parameters of the model can be directly identified from the major hysteresis loop. This model not only satisfies the rotational loss property, but also improves the accuracy of the core loss computation at alternating fields.

## II. VECTOR PLAY MODEL

### A. Ordinary Vector Play Model

With the vector play model, the evaluation of magnetization  $\mathbf{m}$  from the applied field  $\mathbf{h}$  is performed in two steps. The first step is to calculate,  $\mathbf{h}_{re}$ , the vector play operator, by

$$\mathbf{h}_{re} = \begin{cases} \mathbf{h}_{re0} & \text{if } |\mathbf{h} - \mathbf{h}_{re0}| < r \\ \mathbf{h} - r \cdot \frac{\mathbf{h} - \mathbf{h}_{re0}}{|\mathbf{h} - \mathbf{h}_{re0}|} & \text{if } |\mathbf{h} - \mathbf{h}_{re0}| \geq r \end{cases} \quad (1)$$

where  $r$ , representing the intrinsic coercivity, is a given parameter,  $\mathbf{h}$  is the applied field, and  $\mathbf{h}_{re0}$  is the initial value of  $\mathbf{h}_{re}$ . The second step is to derive magnetization  $\mathbf{m}$  from

$$\mathbf{m} = M_{an}(h_{re}) \cdot \mathbf{h}_{re} / h_{re} \quad (2)$$

where  $M_{an}(h_{re})$  is the anhysteretic curve, and  $h_{re}$  is the absolute value of  $\mathbf{h}_{re}$ .

The physical understanding of (1) is: if the applied field  $\mathbf{h}$  is decomposed into two components, the reversible and irreversible components, then the vector play operator represents the reversible component  $\mathbf{h}_{re}$ , and  $\mathbf{h} - \mathbf{h}_{re}$  stands for the irreversible component  $\mathbf{h}_{ir}$ .

The vector play operator of (1) can be illustrated by the vector diagram as shown in Fig. 1.

Draw a circle at the tip of vector  $\mathbf{h}_{re0}$  with radius  $r$ . If the tip of the applied field  $\mathbf{h}$  falls inside the circle, keep the reversible component unchanged, as shown in Fig. 1(a); otherwise, get  $\mathbf{h}_{ir}$  in the direction of  $\mathbf{h} - \mathbf{h}_{re0}$  with length of  $r$ , and then let  $\mathbf{h}_{re} = \mathbf{h} - \mathbf{h}_{ir}$ , as shown in Fig. 1(b).

### B. Improved Vector Play Model

In Fig. 1, if the applied field rotates, it can be proved that at the steady state, the irreversible component  $\mathbf{h}_{ir}$  will be perpendicular to the reversible component  $\mathbf{h}_{re}$ . In the ordinary model, the magnitude of  $\mathbf{h}_{ir}$  is constant no matter how large the applied field is, which means  $\mathbf{m}$ , in the same direction of  $\mathbf{h}_{re}$ , will always lag  $\mathbf{h}$  a certain angle. Therefore, the ordinary vector play model does not satisfy the rotational loss property.

The model can be modified to satisfy the rotational loss property by defining  $r$  as a function of the reversible field component  $h_{re}$  with  $r = 0$  when  $h_{re} \geq h_s$ , here  $h_s$  is the saturation field. The vector play operator then becomes

$$\mathbf{h}_{re} = \begin{cases} \mathbf{h}_{re0} & \text{if } |\mathbf{h} - \mathbf{h}_{re0}| < r(h_{re0}) \\ \mathbf{h} - r(h_{re}) \cdot \frac{\mathbf{h} - \mathbf{h}_{re0}}{|\mathbf{h} - \mathbf{h}_{re0}|} & \text{if } |\mathbf{h} - \mathbf{h}_{re0}| \geq r(h_{re0}) \end{cases} \quad (3)$$

Fig. 2 compares the improved play operator with the ordinary one.

Since  $r$  in (3) depends on  $h_{re}$ , an iterating process is required to solve (3). An efficient iteration algorithm with optimized relaxation factor will be introduced in the full paper.

## III. PARAMETER IDENTIFICATION

The parameters for the improved vector play model, including  $M_{an}(h_{re})$  and  $r(h_{re})$ , are identified from the major hysteresis loop. The major hysteresis loop consists of the ascending branch  $M_{asd}(h)$  and the descending branch  $M_{dsc}(h)$ . The ascending, or descending, curve can be directly obtained from each other based on the odd symmetry condition, and therefore, only one branch is required from input.

If the inverse functions of  $M_{asd}(h)$  and  $M_{dsc}(h)$  are denoted as  $H_{asd}(m)$  and  $H_{dsc}(m)$ , respectively, as shown in Fig. 3, then

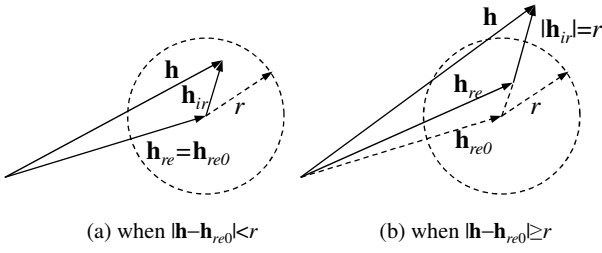


Fig. 1. Vector diagram for vector play operator

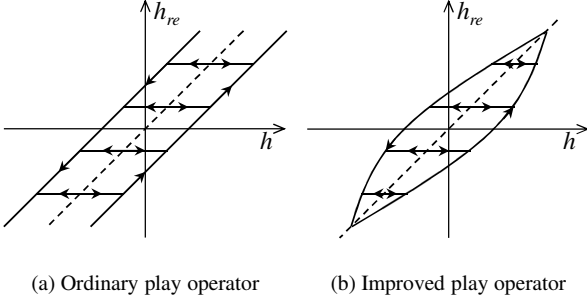


Fig. 2. Comparison between the ordinary and improved play operators

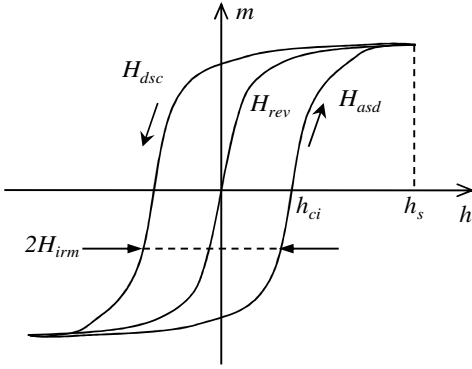


Fig. 3. Magnetic hysteresis loop for parameter identification

$$\begin{cases} H_{rev}(m) = [H_{asd}(m) + H_{dsc}(m)]/2 \\ H_{irm}(m) = [H_{asd}(m) - H_{dsc}(m)]/2 \end{cases} \quad (4)$$

Finally, one obtains

$$\begin{cases} M_{an}(h_{re}) = H_{rev}^{-1}(h_{re}) \\ r(h_{re}) = H_{irm}(M_{an}(h_{re})) \end{cases} \quad (5)$$

#### IV. VALIDATION AND APPLICATIONS

A measured major loop, cited from [10], is shown in Fig. 4, compared with the simulated major loop using the proposed model. Since the parameters are identified directly from the measured major loop, the simulated results are identical with the measured data. The major-loop energy loss per cycle simulated by the improved play model, together with that by the ordinary play model, is compared with the measured data in Table I. The steady-state rotational loss simulated by the improved play model is compared with that by the ordinary play model in Fig. 5.

The proposed model has been implemented in 2D and 3D transient FEA solvers, some 2D and 3D applications will be presented in the full paper.

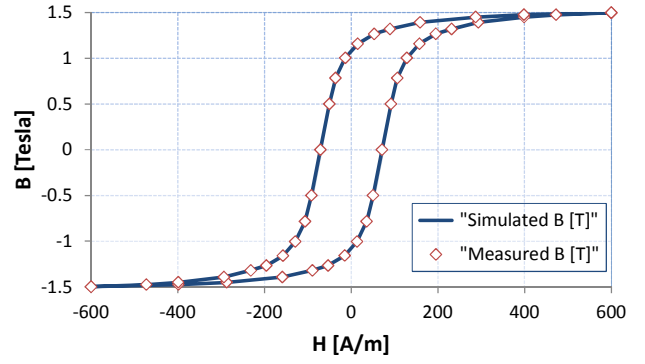


Fig. 4. Simulated major loop by the improved play model compared with the measured one

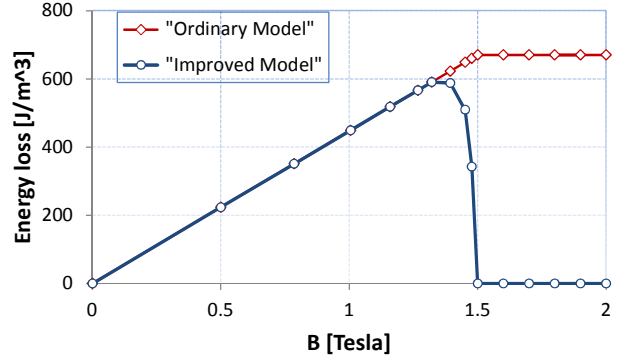


Fig. 5. Rotational loss varying with the magnitude of the rotating flux density

TABLE I  
MAJOR-LOOP ENERGY LOSSES AT ALTERNATING FIELDS

	Energy loss [J/m <sup>3</sup> ]
Simulated by ordinary play model	426.7
Simulated by improved play model	416.5
Measured	416.5

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