

Comparison of Computation Accuracy of Play Models Identified from Everett Function with B-input and H-input

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This paper examines the computation accuracy of the play models with B-input and H-input, whose shape functions are identified from the Everett function, by comparing their computational hysteresis loops with the measured ones. As a result, it was revealed that there is a significant difference in the computation accuracy between the play models with B-input and H-input for the asymmetric hysteresis loop, though their computation accuracy is equivalent for the symmetric one.

Index Terms—Everett function, hysteresis, particle accelerator, play model.

I. INTRODUCTION

THE PARTICLE accelerator system requires high-precision irradiation, especially for particle beam cancer treatment. To further improve the accuracy and speed of beam commissioning, it is essential to generate a magnetic field considering the effects of magnetic hysteresis behavior in the iron core of the accelerator electromagnets.

Various quantitative hysteresis models have been proposed in previous studies, targeting electric machines, including electric motors. Among them, the play model [1], which is equivalent to the static Preisach model [1], [2], has been actively utilized in the design and analysis of electric machines [3], [4]. The play model can flexibly express a relatively wide range of hysteresis characteristics by multiplying the play hysterons with various widths and the shape function [1]. The shape function can be identified from the Everett function [5], because of its equivalence to the static Preisach model. This method can deterministically obtain a shape function whose number of parameters is $N(2N+1)$, where N is the number of measured major hysteresis loops [5] (e.g., when $N = 10$, the number of parameters is 210), so the experimental results of major hysteresis loops can be reproduced with high accuracy. Hence, when implementing the play model for applications requiring extremely high computation accuracy, such as accelerator magnets, it is suitable to identify its shape function using the Everett function. The play model identified from the

Everett function can be implemented by using either the magnetic flux density B or the magnetic field H as the input, where B-input has been traditionally applied to the finite element method (FEM) with A-formulation [6] in the electric machine field. On the other hand, in the particle accelerator field, H-input is preferable since the FEM with H-formulation is generally used.

Therefore, this paper examines the computation accuracy of play models with B-input and H-input identified from the Everett function, comparing their computational hysteresis loops with the measured ones.

II. COMPARISON OF COMPUTATION ACCURACY OF PLAY MODELS WITH B-INPUT AND H-INPUT

A. Identification of play models

To identify a shape function of the play model using the Everett function, it is generally required to acquire measurement data of major hysteresis loops with equally spaced maximum values. In the case of B-input, several dozen measured hysteresis loops are generally required to achieve sufficient computation accuracy, where intervals between their maximum magnetic flux densities are several tens of millitesla. Fig. 1 shows the measured hysteresis loops of non-oriented silicon steel (NOES), whose maximum magnetic flux density B_m is from 0.05 to 1.45 T at intervals of 0.05 T. On the other hand, in the case of H-input, many more hysteresis loops must be measured to achieve the same computation accuracy as B-

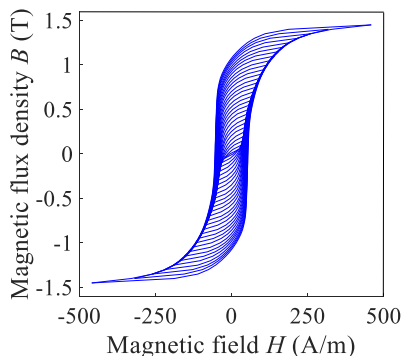


Fig. 1. Measured major hysteresis loops (B_m = from 0.05 to 1.45 T at intervals of 0.05 T).

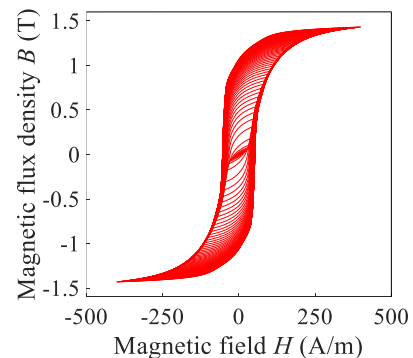


Fig. 2. Interpolated major hysteresis loops (H_m = from 5 to 400 A/m at intervals of 5 A/m).

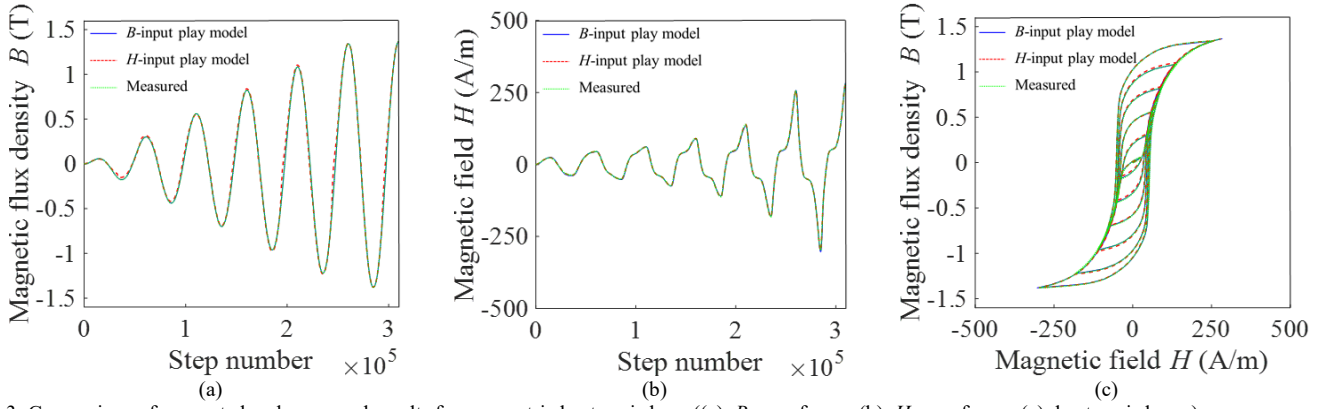


Fig. 3. Comparison of computed and measured results for symmetric hysteresis loop ((a): B waveforms, (b): H waveforms, (c): hysteresis loops).

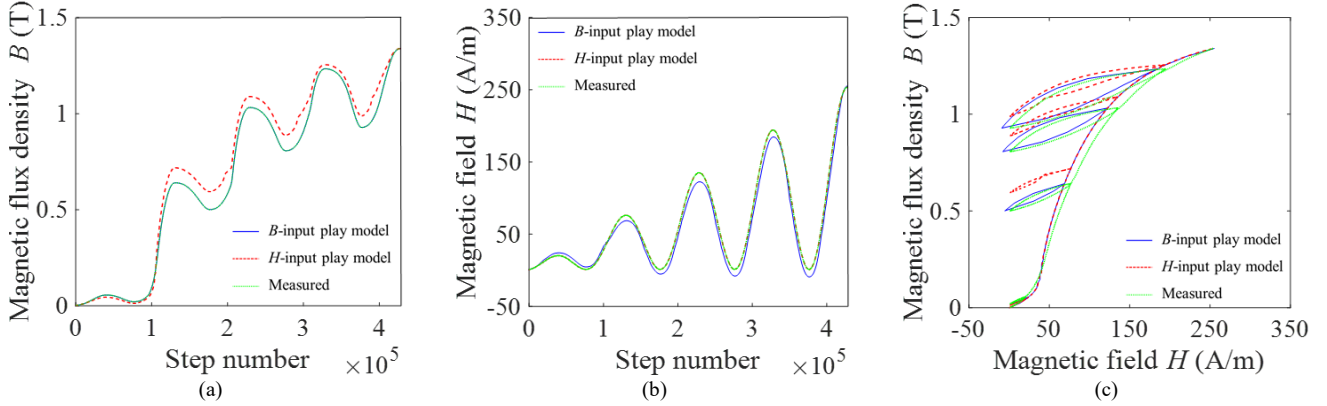


Fig. 4. Comparison of computed and measured results for asymmetric hysteresis loop ((a): B waveforms, (b): H waveforms, (c): hysteresis loops).

input, where intervals between their maximum magnetic fields are a few amperes per meter. Therefore, in this paper, to reduce the amount of measurement data, hysteresis loops generated by interpolation [7] are substituted for measured ones when implementing the play model with H-input. Fig. 2 shows the interpolated hysteresis loops of NOES, whose maximum magnetic field H_m is from 5 to 400 A/m at intervals of 5 A/m.

B. Simulation results

In this section, the computational results of play models with B-input and H-input are compared with the experimental ones of NOES under several excitation conditions. The shape function is identified from the measured hysteresis loops shown in Fig. 1 for B-input and the interpolated hysteresis loops shown in Fig. 2 for H-input, respectively. The play models with B-input and H-input are implemented by inputting the measured waveforms of B and H , respectively.

Figs. 3 and 4 compare the computed and measured results in the cases of the symmetric and asymmetric hysteresis loops, respectively. As shown in Fig. 3, all three waveforms are in good agreement in the case of the symmetric hysteresis loop. On the other hand, as shown in Fig. 4, the computed waveforms of the B-input play model well match the measured ones, while there are relatively large errors for minor loops between the computed waveforms of the H-input play model and the measured ones, in the case of the asymmetric hysteresis loop. The specific problems are the differences in the magnetic flux density regions of minor loops and the area of minor loops due to their unnatural shapes of ascending curves. The difference in

their computation accuracy is thought to be due to their shape functions. The authors will present the causes in detail in the full paper.

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