

A Stable and Fast Fixed-point Technique for Solving Magnetic Field Problems under Non-sinusoidal Excitation

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In this paper, a new fixed-point technique for solving magnetic field problems under non-sinusoidal excitation is proposed. Since hysteresis is branching, discontinuing the derivative at the reversals could become problematic when implementing the local-coefficient method (LCM). To enhance convergence stability at the reversal points, typical approaches usually employ a large fixed-point coefficient. However, this approach considerably impedes the convergence speed, especially in the cases of multiple reversal points under non-sinusoidal excitation. Therefore, a new fixed-point technique is developed, incorporating the Anderson acceleration with LCM. This method aims to substantially accelerate the iterative convergence speed while guaranteeing the overall convergence of the iterative process. Finally, the effectiveness of the proposed technique is rigorously validated through a comparative analysis of the computational costs incurred in numerical simulation experiments.

Index Terms—Finite element method, fixed-point method, magnetic field, nonlinear hysteresis.

I. INTRODUCTION

The incorporation of hysteresis within the finite element analysis (FEA) is essential for accurately predicting the residual flux distribution within transformers and conducting a thorough analysis of loss characteristics in electrical machines.

In solving magnetic field problems of hysteretic magnetic media via the finite element method (FEM), since dealing with the multi-valued hysteresis problems depends on the implementation of the nonlinear iterative algorithm, the convergence of the fixed-point method (FPM) becomes a crucial problem. Compared to other nonlinear iterative algorithms, such as the Newton-Raphson method, the FPM is extensively utilized for solving problems of hysteretic magnetic media due to its outstanding robustness and simple iterative form. However, the traditional FPM has a very slow convergence speed making it difficult to apply it to time domain FEM directly. Thus, in time-stepping FEA, Dala proposed the local-coefficient method (LCM), which accelerates the convergence at the non-reversal points by determining fixed-point coefficients via the utilization of differential reluctivities[1]. Nevertheless, since the branching nature of the hysteresis, the differential reluctivities at the reversal points cannot be predicted accurately, and larger fixed-point coefficients are required to ensure stable convergence at these points, which also results in a significant decrease in the convergence speed at the reversal points. To address this problem, Yue recently proposed a fixed-point technique to further improve the convergence speed by adaptively adjusting the convergence factor of LCM at the reversal points[2]. However, under non-sinusoidal excitation, the case of multiple reversal points drastically increases the time to adjust the convergence factor, resulting in a significant increase in overall computation time.

Based on classical extrapolation theory, the Anderson Acceleration (AA) exhibits excellent performance in solving

nonlinear problems. It is expected to provide new insights for improving the speed of fixed-point solutions[3]. Therefore, to enhance the convergence of the FPM in solving the multi-valued hysteresis problems under non-sinusoidal excitation, a new fixed-point technique that incorporates the LCM and AA is proposed in this paper.

II. DETERMINATION OF FIXED-POINT COEFFICIENT AT REVERSAL POINTS

In the time-stepping analysis of the hysteresis magnetic field, the LCM determines the fixed-point coefficient based on differential reluctivities, which are calculated from the backward difference formulation:

$$v'_{FP} = C \left(\frac{H^{t-1} - H^{t-2}}{B^{t-1} - B^{t-2}} \right), \quad C > 1 \quad (1)$$

Where v_{FP} is the fixed-point coefficient, C is the convergence factor, t is the time step, H is magnetic field intensity, and B is magnetic flux density.

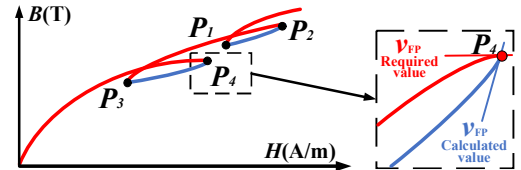


Fig. 1 Difference between the calculated fixed-point coefficient and the required one at a reversal point

As illustrated in Fig.1, there is a difference between the fixed-point coefficient calculated from solving the equation (1) and the required fixed-point coefficient at a reversal point, which causes the iteration to diverge at the reversal point. Therefore, the fixed-point coefficient at the reversal point will be calculated by the following equation:

$$v'_{FP} = \frac{v_0}{2} \quad (2)$$

Where v_0 is the reluctivity of the vacuum. According to the contraction mapping principle, the contraction factor of this

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