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Defect Evaluation in Mild Steel Plate Using Harmonic Ratio Induced by Square Wave Excitation Field and Nonlinear Magnetization

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Similar to multi-frequency techniques in eddy current and magnetic flux leakage testings, the harmonic evaluation technique using a square wave excitation field improves the defect detection performance of conductive materials compared to single-frequency techniques. However, in the case of mild steel, its nonlinear frequency-dependant magnetization impacts the intensity and phase of the induced harmonics. In this work, we propose a harmonic ratio technique using a square wave excitation field to enhance defect detection in mild steel. A custom-made probe with a planar differential tunnel magnetoresistance sensor and inductor arrays was developed to assess the harmonic responses induced by artificial slits on a 12-mm mild steel. The harmonic dependency on the slit depth, excitation frequency, and intensity was evaluated. The results showed that the ratio of the two highest harmonics exhibited a correlation with slit depth, accompanied by a significant reduction in baseline signal drift as compared to the single-frequency detection mode. It was shown that the proposed harmonic ratio technique, leveraging a square wave excitation field, significantly enhances sensitivity and immunity to background signal drift, thereby improving defect detection capabilities in mild steel.

***Index Terms*— eddy current, harmonics, mild steel, square wave, tunnel magnetoresistance.**

I. Introduction

DETECTING and monitoring defects in critical steel structures, such as pipelines and bridges, is imperative to prevent potential catastrophic accidents. Non-destructive testing based on electromagnetic methods plays a crucial role in this regard, with magnetic particle inspection, magnetic flux leakage (MFL), and variations of eddy current (EC) techniques demonstrating significant promise [1], [2]. While frequency-dependent electromagnetic methods like the EC techniques can provide more comprehensive information about defect properties in conductive materials, the strong ferromagnetic nature of mild steel imposes limitations on EC's penetration depth, thereby reducing its effectiveness for inspecting deeper defects [3]. Conventionally, frequency-independent MFL has been used for ferromagnetic material inspection, and researchers have been developing low-frequency techniques, such as AC magnetic flux leakage (ACMFL) and pulse eddy current (PEC), to evaluate deeper defects [4], [5].

Multi-frequency methods in EC and MFL techniques, such as the PEC technique, have gained widespread adoption for defect evaluation in steel, showcasing enhanced detection capabilities compared to traditional EC or MFL techniques [6], [7], [8]. Within the PEC technique, the magnetic response encompasses multi-frequency signals (harmonics), with each frequency spectrum corresponding to distinct penetration depths [9]. Additionally, the ACMFL technique, when combined with low- and high-frequency excitation, has facilitated accurate detection of the size and orientation of surface and backside defects in steel plates [4], [10]. Moreover, the fusion of rich information from multi-frequency or harmonic responses allows for the identification of small defect signals in the presence of noise or larger signals from structural irregularities [11].

Similar to the PEC technique, a rectangular wave EC technique has been developed, offering a simpler implementation of excitation electronic circuits while retaining the advantage of the multi-frequency EC technique [12], [13]. In [13], EC harmonics were utilized for defect detection in aluminum plates, revealing a correlation with the depth location of defects within the material. Apart from its capability to distinguish accurately between surface and back-surface defects, its simpler electronic setup for inducing rectangular EC compared to the use of conventional linear amplifiers would lead to more compact EC probes.

Expanding the harmonic evaluation technique, we explore the feasibility of using a square wave EC for detecting defects in mild steel components. Unlike aluminum, the generated harmonic responses can be influenced by the nonlinear magnetization of mild steel, where the effectiveness of the rectangular EC technique in such materials should be clarified.

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