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Backside Defect Evaluation in Carbon Steel Plate Using a Hybridized Magnetic Flux Leakage and Eddy Current Technique

Mohd Aufa Hadi Putera Zaini[1] · Mohd Mawardi Saari[1,2] · Nurul A'in Nadzri[1] · Zulkifly Aziz[1] · Toshihiko Kiwa[3]

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Abstract
The challenges inherent in effective nondestructive evaluation of backside defects in steel, such as cracks, arise from the limited penetration of eddy currents (EC) due to the high permeability of steel. While the magnetic flux leakage (MFL) technique is able to detect deep defects, it lacks detailed geometry information. In this study, a hybrid approach is proposed, involving the simultaneous analysis of MFL and EC signals using a custom-designed magnetic probe. The probe is developed based on Finite Element Method simulations, followed by validation on 2 mm carbon steel plates containing artificial slits. The simulation results showed that the spatial and intensity responses of MFL and EC signals within the slits can be utilized for characterizing the slits. Furthermore, validation with fabricated backside slits confirms the correlation between slit depth, length and the intensity of the measured signals, particularly when an optimized excitation frequency is employed. The proposed method enables the prediction of slit depth and identification of slit shapes, thereby resulting in an enhancement of backside defect detection capabilities. Through this proposed hybrid technique, a connection is established between MFL and EC methods to enable a versatile tool for the precise assessment of cracks.

Keywords Magnetic flux leakage (MFL) · Eddy current testing (ECT) · Finite element modelling (FEM) · Phase-sensitive detection · Slit detection · Steel · Anisotropy magnetoresistance (AMR)

1 Introduction

Cracking in steel structures remains a common issue that compromises their safety [1]. Various factors contribute to crack formation, with fatigue being a significant cause due to continuous stress and strain [2, 3]. These cracks often exhibit diverse shapes and sizes, ranging from micrometer dimensions to sizes that can lead to substantial structural concerns. Consequently, nondestructive evaluation (NDE) techniques are employed to detect newly formed cracks in operational structures, mitigating the risk of catastrophic damage.

Numerous NDE methods are in use, including visual inspection [1, 4], radiography [5, 6], ultrasonic [7, 8] and electromagnetic [9, 10] techniques. Among these, the electromagnetic approach stands out due to its rapid, real-time scanning capability and utilization of contactless electromagnetic waves for defect detection, even on metal surfaces covered by insulators. Notably, two prominent techniques within this domain are magnetic flux leakage (MFL) [11, 12] and eddy current technique (ECT) [13–16].

The MFL technique is conventionally employed to assess surface defects in steel, capitalizing on the steel's high magnetic permeability. Utilizing a static magnetic field for magnetization simplifies the detection principle of leakage flux, enabling the convenient identification of deep defects in thick ferromagnetic samples. Nonetheless, many MFL-based techniques necessitate magnetic saturation of the sample, imposing the need for a robust current source to generate the excitation field. However, Hayashi et al. [17] demonstrated that magnetic saturation becomes dispensable when

✉ Mohd Mawardi Saari
mmawardi@ump.edu.my

1 Faculty of Electrical and Electronic Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia

2 Centre for Advanced Industrial Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia

3 Graduate School of Interdisciplinary Science and Engineering in Health Systems, Okayama University, Okayama 700-8530, Japan

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