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Enhanced detection of deep seated flaws in 316 stainless steel plates using integrated EC-GMR sensor

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ABSTRACT

Eddy current electromagnetic non-destructive evaluation technique is widely used for detection and sizing of flaws in electrically conducting materials within a depth of 5.0 mm. In order to extend the application of EC technique for detection of deep seated flaws (>5.0 mm), an integrated sensor comprising of EC coil and a Giant magnetoresistive sensor has been developed. The experimental measurements and Finite Element Model based studies on 8.0 mm thick AISI type 316 stainless steel plate having machined surface and subsurface notches at different depth location have been investigated. The paper discusses the detection sensitivity of components of induced magnetic field for deep seated flaws under varying lift-off condition.

1. Introduction

Non-destructive evaluation (NDE) plays a major role in guaranteeing structural integrity of engineering components through detection and sizing of flaws. It is important to detect flaws in the components at the early stage to prevent catastrophic failure. Among NDE techniques, eddy current (EC) technique is preferred for testing of electrically conducting non-ferromagnetic materials because of its versatility, ease of operation and high sensitivity. In EC testing, small changes in impedance of a coil due to distortion of induced eddy currents at flaw regions are measured. For quantitative evaluation of flaws, magnitude and phase angle of the impedance change is used. The technique is in general confined to detect the flaws within a depth of 5.0 mm due to the exponential decay of eddy currents [1]. Although, lowering of excitation frequency enhances the depth of penetration of eddy currents, feeble strength of the magnetic fields limits the detection sensitivity of coils for deep seated flaws (>5.0 mm). Hence, use of a high sensitive magnetic field sensor is imperative for measurement of weak magnetic fields from such flaws. Giant magnetoresistance (GMR) sensor as receiver is attractive due to its high sensitivity for weak magnetic fields, superior spatial resolution and wide frequency range capability [2,3]. Jeng et al. used GMR based eddy current sensor for detecting subsurface flaws in multilayer aluminium sheets of 1.0 mm thickness [4]. Matteo et al. used GMR based eddy current sensor for detection of micro flaws in high density printed circuit boards [5]. Postolache et al. used horizontal component of magnetic field measured from GMR sensor for classification of surface flaws and through holes using neural network based algorithms [6].

Helena Ramos et al. used GMR sensor for detecting surface flaws in thin aluminium plates by measuring vertical component of magnetic field [7]. Pasadas et al. utilised response of GMR sensor for mapping magnetic field near surface flaw in a 4.0 mm thick aluminium plate [8,9].

From literature survey, GMR sensor is found to be an effective tool for measuring feeble magnetic field components. In addition, higher spatial resolution of GMR sensor is found advantageous for detection of deep lying fine cracks.

The early detection of deep seated flaws in the components such as storage tanks with thickness in the range of 6.0–8.0 mm will be beneficial for ensuring safety and reliability of the component. Hence, this study focuses on development of single sensor for surface as well as sub-surface flaw detection in an installed thick (>5.0 mm) components. In view of this, authors have envisaged a design and development of an integrated eddy current-GMR (EC-GMR) sensor which comprises a coil for generation of eddy cur-

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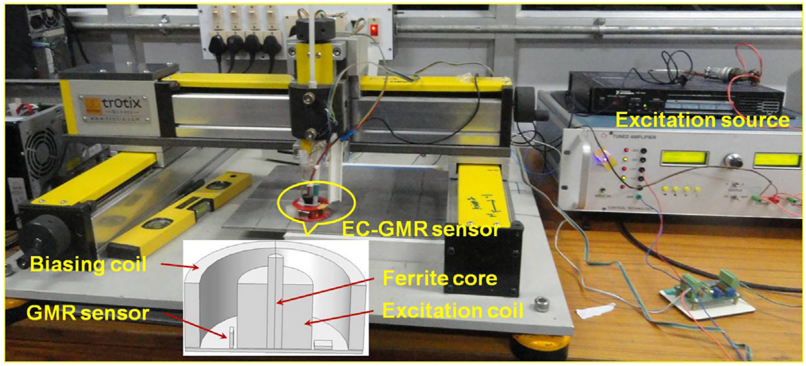

Fig. 1. Eddy current GMR measurement system.

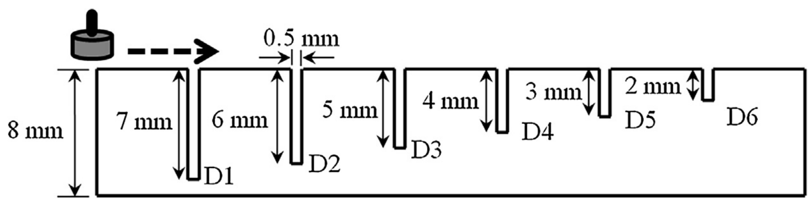

Fig. 2. Schematic view of SS plate having surface flaws.

rents in the material and GMR sensoras receiverfor measuring the induced magnetic field.

Primarily to understand the response of induced magnetic field across the surface and sub-surface flaws,the sensitivity of horizontal (B_x) vertical (B_z) components of induced magnetic field needs to be studied. The authors have a carried out Finite element model (FEM) based study to predict the distribution of induced magnetic field components across the flaw location. Using GMR sensors, magnetic field components (B_x and B_z) across the surface and sub-surface flaws has been carried out and discussed in this paper. The detection sensitivity among B_x and B_z components of the magnetic field across the flaws has been compared by the use of amplitude and phase angle parameters. This paper also explores the possible sensitive parameter for enhanced detection of deep seated flaws under varying lift-off (stand off distance between probe and surface of the specimen) condition.

In this paper, Section 2 covers the configuration of the EC-GMR sensor and measurement system. Section 3 discusses the model predictions; Section 4 covers the experimental observations for surface and subsurface flaws followed by conclusions in Section 5.

2. Eddy current GMR system

The integrated EC-GMR sensor comprises of (i) an excitation coil (ferrite cored, 10.0 mm outer diameter, 50 turns) driven by sinusoidal current of 100 mA at frequency of 1 kHz, (ii) two GMR sensors (NVE AA002-04) mounted adjacent to the excitation coil and (iii) DC biasing coil for fixing the operating point of the GMR sensors. In order to enable simultaneous measurement of B_x and B_z components of induced magnetic field, sensitive axis of the two GMR sensors are oriented parallel and perpendicular to the scanning surface, respectively. The photograph of the integrated EC-GMR sensor system is shown in Fig. 1. The integrated EC-GMR sensor is mounted on the arm of XY scanner for automated scanning. The response from the GMR sensors are conditioned through a low pass filter circuit and acquired using a data acquisition card (16 bit, 250 kS/s). For separation of phase angle and amplitude information from the acquired signal, I/Q detection technique based digital lock-in amplifier is implemented in LabVIEW environment [10,11].

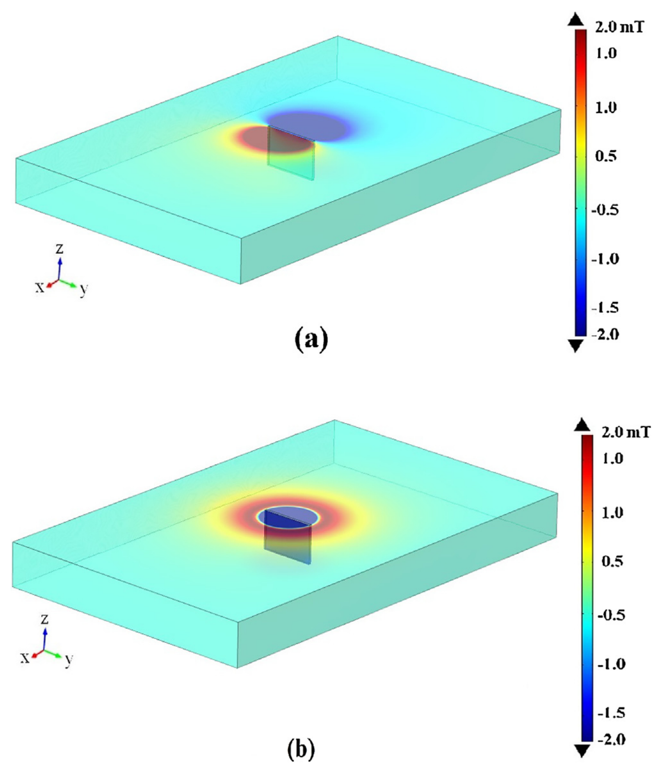

Fig. 3. FEM predicted variation in (a) Bx and (b) Bz component across surface flaw of depth 6.0 mm.

Primary study involves FEM based prediction of magnetic field distribution across the surface flaws in a 8.0 mm thick 316 SS plate. The schematic view of the SS plate considered for this study, with electro discharge machined notches of varying depths from 2.0 mm to 7.0 mm, on one side, is shown in Fig. 2.