Sensors and Actuators A 157 (2010) 26–31

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Defect classification based on rectangular pulsed eddy current sensor in different directions

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ARTICLE INFO

Article history:
Received 21 August 2009
Received in revised form
25 September 2009
Accepted 15 November 2009
Available online 22 December 2009

Keywords:
Pulsed eddy current (PEC)
Rectangular exciting coil
Defect classification
Feature extraction

ABSTRACT

Pulsed eddy current (PEC) testing is a new emerging and effective electromagnetic non-destructive testing (NDT) technique. The main purpose of this study is to identify surface defects and sub-surface defects using features-based rectangular pulsed eddy current sensor. The further study of PEC rectangular sensor proposed in author's previous work has been made to classify the different types of defects in specimen. In different directions of sensor scanning, peak waves of pick-up coil are studied. We find that when sensor is on different position against the defect, peak waves of response signals present the same shape in direction of magnetic induction flux, while present different shapes in direction of exciting current. Experiment results have shown that the different classes of defects can be identified and classified effectively by selecting the rising time as the time domain feature in both directions. For improving the performance of defect classification, two new features from differential response signal are proposed to classify different types of defects combined with rising time. One is called as crossing time; the other is differential time to peak. The blind test is carried out and the results show that the new features are effective to classify the defects.

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1. Introduction

The pulsed eddy current (PEC) non-destructive testing is a new technology developed in recent years, which is an effective method that has been demonstrated to be capable of quantifying defects in the multi-layer structures [1–3]. PEC testing possesses many advantages against the conventional eddy current testing, including more extended detection depth, richer information about defects and higher robustness of anti-interference. In addition, PEC testing technology taking pulse as excitation can minimize power consumption, which is more promising in the development of portable instrument [4,5].

Rose et al. described the defect detection in time domain for both air-core and ferrite-core PEC probes with one flat coil [6]. Giguere et al. illustrated three features adopted in PEC testing to quantify defects and exemplify their application [7]. Sophian et al. introduced the application of principal component analysis in extracting features from PEC response [8]. Tian et al. presented a new feature called as rising point time to identify the different defect types and lift-off, which offers benefits such as independence of coil dimension and ability to evaluate a defect's depth regardless of its type or shape [9]. They (2005) also presented a new approach for defect classification and quantification by using pulsed eddy current sensors and integration of principal component analysis and wavelet transform for feature-based signal interpretation [10]. Chen et al. extracted and selected appropriate features for defect classification of pulse eddy current [11]. In all these studies, the cylindrical driving coil is excited by repeated pulses and the response signals are measured with a sensor, which may be the driving coil, another coil, or a Hall sensor. As shown in Fig. 1, the probe in Tian's work consists of the cylindrical excitation coil windings and the hall devices [12,13].

However, rectangular exciting coil has not been proposed in PEC testing which are likely to be capable of detecting and identifying defects. In authors' laboratory, Yang and Luo proposed peak value and over-zero time of response signal, respectively, to measure the length and depth of defect [14,15]. They (2007) also did a research on edge identification of a defect using pulsed eddy current based on principal component analysis [16]. In 2009, three-dimension pick-up coils are proposed and defects on surface can be identified and evaluated effectively [17]. The main purpose of this paper is to classify the defects both on surface and sub-surface based on rectangular pulsed eddy current sensor.

The rest of the paper is organized as follows. Firstly, experimental system including hardware and specimen is established in Section 2. Next, different directions of sensor scanning are introduced in Section 3. Then, experiment results in different scan-

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doi:10.1016/j.sna.2009.11.012

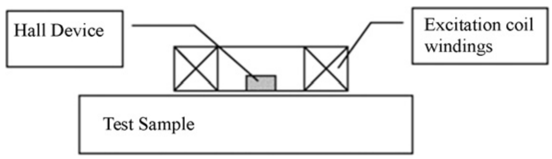

Fig. 1. Cylindrical probe in Tian's work.

ning directions are shown and the new features are presented in Section 4. Finally, conclusions and further work are outlined in Section 5.

2. Experimental system

Experimental system is designed to produce pulses and to measure the transient response signals affected by defects in specimen. The PEC experimental system used in this research consists of pulse generator, power amplifier, probe, specimen, signal process, data acquisition module, and software. The generator module is used to generate the exciting pulse. The power amplifier is employed to enhance the power of exciting signal. The probe is used to induce the response signals. The response signals are amplified by signal processing module. Then, the response signals are sampled by data acquisition module with 100 kHz sampling rate. Software is programmed by Microsoft Visual C++ 6.0, combined with Matlab 7.0.

To verify performance of the PEC system, an aluminum specimen is designed for surface and sub-surface defects detection and classification. On the surface, some slots with the same length (15 mm) but different depths and widths are manufactured to simulate corrosion type defects in real situation. The length × width × depth of defects respectively are 15 mm × 8 mm × 2 mm, 15 mm × 6 mm × 2 mm, 15 mm × 4 mm × 2 mm, 15 mm × 5 mm × 2.5 mm, 15 mm × 5 mm × 2 mm, 15 mm × 5 mm × 1 mm. The thickness of specimen is 3 mm, and the distance between two slots is 50 mm. For surface defect simulation, we place the probe to the surface of specimen, and for sub-surface defect, we place the probe to the other side of specimen.

3. Peak waves in different directions

3.1. Different directions of sensor scanning

As shown in Fig. 2, the probe consists of one rectangular exciting coil and one pick-up coil. The length, width and height of rectangular exciting coil, respectively, are 50, 45 and 45 mm. The number of turns is 400. The pick-up coil is located orthogonally in the center at the bottom of the exciting coil, which are reeled with inductive coil

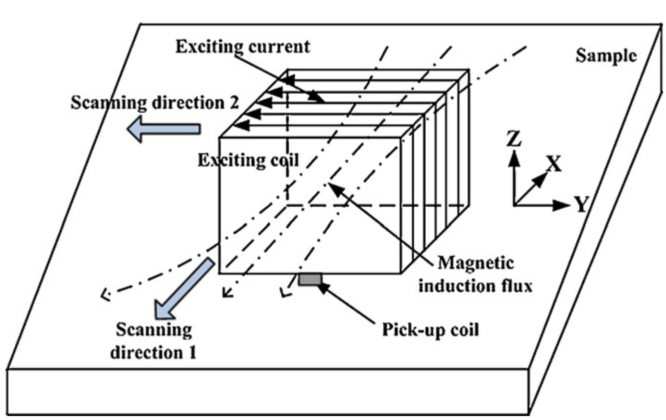

Fig. 2. The diagram of PEC probe scanning direction.

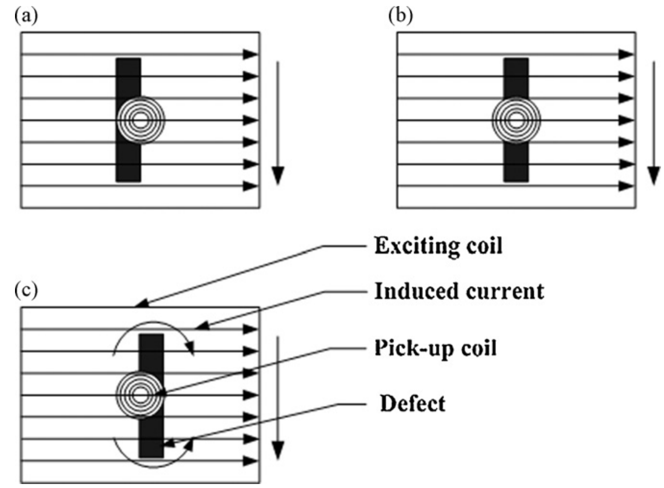

Fig. 3. The scanning forms of sensor in direction of magnetic induction flux: (a) pick-up coil is on the right of defect; (b) defect is on the center of sensor; (c) pick-up coil is on the left of defect.

to induce the change of magnetic fields along the scanning path. The turn of pick-up coil is 1000.

In authors' previous studies, voltage waves of 3D magnetic field are analyzed in different directions of sensor scanning [17]. One is the direction of magnetic induction flux; the other is the direction of exciting current. Considering the orientation of the coil to the specimen, a Cartesian coordinate system is introduced. As shown in Fig. 2, the direction of magnetic induction flux is parallel to *X*-axis and the direction of exciting current is parallel to *Y*-axis. In the course of probe scanning, the response signal of each pick-up coil is sampled in real time and the periodic peak voltage of each signal is extracted at the same time. Then, the peak voltages are connected. Consequently, peak waves of defect response signals form.

3.2. Peak waves

In this experiment, the amplitude of the exciting pulse is 10 V, the repetition rate of the excitation is 100 Hz and the pulse duration is 5 ms. As shown in Figs. 3 and 4, there are three kinds of

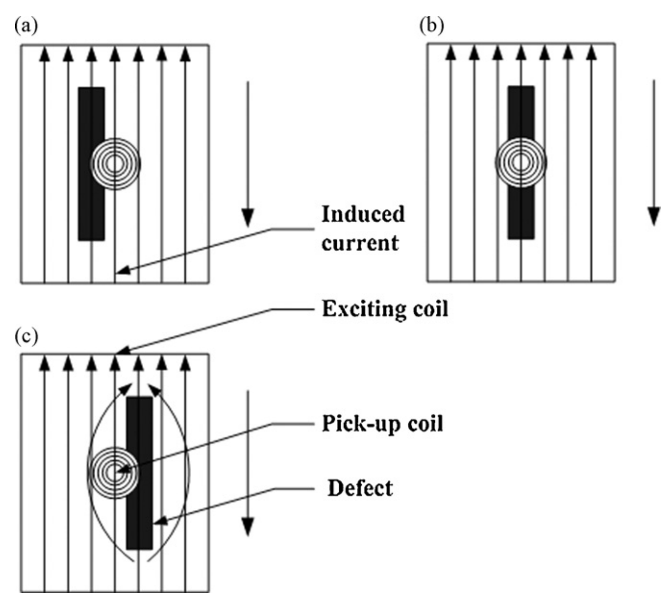

Fig. 4. The scanning forms of sensor in direction of exciting current: (a) pick-up coil is on the right of defect; (b) defect is on the center of sensor; (c) pick-up coil is on the left of defect.

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