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Defect characterisation based on pulsed eddy current imaging technique

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ABSTRACT

The pulsed eddy current (PEC) technique is an emerging electromagnetic method, which is widely applied to detect defects in the field of nondestructive testing and evaluation (NDT&E). This paper studied the PEC imaging technique to identify and evaluate the corrosion type of defects. Based on PEC probe consisting of a rectangular exciting coil and an induction pick-up coil, the C-scan imaging technique is researched and analyzed in two directions (magnetic induction flux and exciting current). The averaging method and wavelet transform are used to de-noise the response PEC signals. Experiment results have shown that the corrosion type of defect can be identified effectively by particular character based on rectangular exciting coil in both directions, and that the results in direction of magnetic induction flux are more effective than those in direction of exciting current. Defect characterisation is carried out based on the C-scan image. The defects are discriminated to surface defect by selecting the rising time as the feature and the sizing of defects are preliminarily obtained based on the imaging results. To sum up, the PEC imaging technique is an effective means to evaluate the corrosion type of defects, which can be extended to the characterisation of complex defects.

1. Introduction

The pulsed eddy current testing developed in recent decades can be used to measure the parameters of metal such as thickness and conductivity [1,2]. Moreover, the PEC testing is one of the most effective NDT&E methods, which has been demonstrated to be capable of tackling different inspection tasks, such as sub-surface defect detection in complex structures [3–5]. On one hand, PEC testing can be applied to non-magnetic conductive test pieces in contrast to magnetic particles inspection. It does not require an acoustic couplant as ultrasonic inspection does and it is more economical applied than radiography [6]. On the other hand, PEC testing taking pulse as excitation possesses many advantages against the conventional eddy current testing, including more extended detection depth, richer information about defects, higher robustness of anti-interference, and lower power consumption [7,8]. Therefore, the PEC testing becomes the subject of wide-spread interest in nondestructive testing in recent decades, such as air structures NDT [3,9,10] and has been particularly developed and devised for sub-surface crack measurements, crack reconstruction, and depth estimation [11]. In PEC testing, the response signal is measured with a pick-up coil, a differential probe [8,12], a magneto-resistive sensor [13], a giant magneto-resistive (GMR) sensor [14–16], a hall-effect sensor [17–19], or a superconducting quantum interference device (SQUID) magnetometer [20], while the driving unit is usually cylindrical coil, which is excited by repeated pulses to induce eddy current in specimen.

However, rectangular exciting coil which can induce uniform eddy current in specimen [21,22] has not been used in PEC testing. In our laboratory, rectangular exciting coil was proposed and researched in PEC testing, whose diagram is shown in Fig. 1. The experimental results have indicated that it is also capable of detecting and evaluating defects. In 2006, the rectangular coil was proposed to measure the length and depth of defect in aircraft multi-layered structures [23]. In 2007, the research on edge identification of a defect is studied based on rectangular coil [24]. In 2009, defects on surface are identified and evaluated effectively [25] and the surface defects and sub-surface defects are classified based on rectangular coil [26]. As we know, imaging detection can get the shape of a defect and is more intuitive than traditional nondestructive testing methods. Hence, imaging testing has become the development trend of nondestructive testing apparatus. The main objective of this paper is to research the PEC imaging technique for the purpose of defect characterisation.

The rest of the paper is arranged as follows. Firstly, the principle of PEC imaging is introduced in Section 2. Next, experimental setup including hardware, software, and specimen is established in Section 3. Then, the results of C-scan imaging are displayed in Section 4 and the defect characterisation is shown in Section 5. Finally, conclusions and further work are outlined in Section 6.

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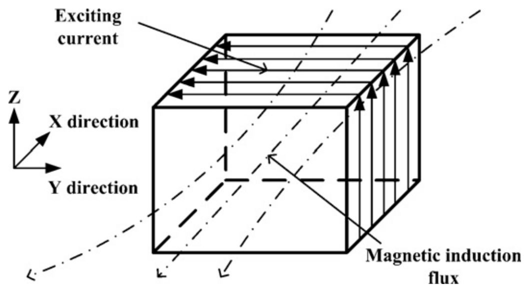

Fig. 1. The diagram of PEC probe.

2. Principle of PEC imaging

In PEC testing, the probe is usually excited with a repetitive pulse. The transient current through the exciting coil induces transient pulse eddy currents in metallic conductive specimen by changing magnetic fields. Physically, the pulse eddy current is broadened and delayed as it travels deeper into the highly dispersive material. Therefore, defect or other anomalies close to the surface will affect the eddy current response earlier in time than deep defect. Typical features from response signals such as peak and zero-crossing time are used to detect and characterise defect [23–25]. In PEC experiments, it was found that the peak amplitude of response signal is proportional to the amount of metal loss. Specifically, the peak amplitude increases clearly with the increment of defect volume. Thus, we select the peak amplitude to obtain the information of defects' volume in this paper.

Operation of C-scan imaging is controlled by the windows-based software. As shown in Fig. 2, the software is comprised of parameter set-up, data acquisition, feature extraction, data process, peak wave display, imaging display, data saving, data playback, and defect characterisation. In the course of probe scanning, the peak amplitude of the transient response signal will be extracted and used as the parameters for C-scan imaging. The color scale of the image is adjusted by the peak amplitude of the transient response signal and the image of C-scan comes into being. The image can be saved after detection and can be played back for the purpose of off-line process and analysis.

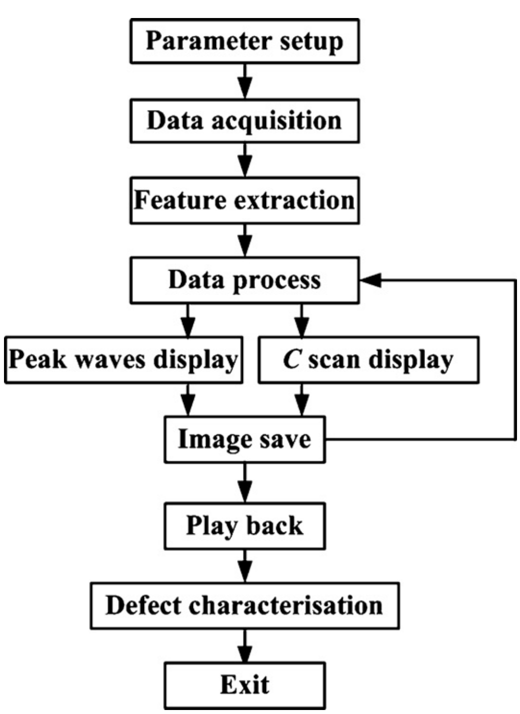

Fig. 2. Schematic flowchart of software.

Table 1
Parameters of the exciting coil and pick-up coil.

Parameters	Exciting coil	Pick-up coil
Wire diameter (mm)	0.2	0.05
No. of turns	400	1000
DC resistance (Ohm)	40.2	165.9
Inductance (mH)	7.75	4.75

3. Experimental set-up

The PEC experimental set-up we developed is a PC-based system, with the key elements contained in an industrial control computer. The mother board of computer houses three printed circuit boards: an excitation card, a signal conditioning card, and an analog to digital converter card. In excitation card, some direct digital synthesizer (DDS) chips AD7008 and comparator circuits are used to generate the exciting pulse. Power amplifier chip Lt1206 is employed to enhance the exciting current. The response signals are two-stage amplified by signal conditioning card, which is comprised of PGA202 and PGA203. Then, the response signals are sampled by data acquisition module with 100 kHz sampling rate [12,26]. The exciting pulse used in this paper is 10 V in amplitude, 100 Hz in frequency, and 5 ms in pulse duration.

Two aluminum specimens whose thickness is 2 mm are designed to verify performance of the proposed method. On the surface, two electron discharge machining (EDM) slots are manufactured to simulate corrosion type of defects in real situation. Hence the dimension of slot is relative bigger than that of crack type of defect. The defect one is 15 mm in length, 5 mm in width, and 1.5 mm in depth and the defect two is 15 mm in length, 2.5 mm in width, and 1.5 mm in depth.

The PEC probe in authors' work consists of one rectangular exciting coil and one cylindrical pick-up coil. The rectangular exciting coil is 50 mm in length, 45 mm in width, and 45 mm in height. The pick-up coil is located orthogonally in the center at the bottom of the rectangular exciting coil to measure the magnetic field rate of change. The inner diameter of the pick-up coil is 1 mm and the height is 2 mm. The lift off of PEC probe is 0.5 mm, which is depending on the core's dimensions. The other characteristics of exciting coil and pick-up coil are shown in Table 1.

4. Results and discussion

4.1. C-scan results

Peak waves of magnetic field disturbed by defect are analyzed in both directions of sensor scanning in our previous studies. One is the direction of magnetic induction flux; the other is the direction of exciting current. 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 [25,26]. In authors' previous work, it is concluded that when sensor scans along the defect, peak waves of response signals always present a crest and a trough in direction of magnetic induction flux, while present different shapes in direction of exciting current [26]. In other words, a crest and a trough always appear on the peak waves when the probe scans along the defect in direction of magnetic induction flux. In direction of exciting current, a broad crest appears on peak waves when defect is on the left of pick-up coil. In contrast, when defect is on the right of pick-up coil, a broad trough appears on peak waves. Therefore, the imaging results in both directions are compared.