QUANTITATIVE EVALUATION OF DEFECT IN STAINLESS STEEL 304 TUBE USING PULSED EDDY CURRENT TECHNIQUE

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Abstract

Pulsed eddy current (PEC) is an advanced non-destructive testing (NDT) technique that operates based on electromagnetic principle. The excitation consists of broad frequency spectrum leading to be a potential in detecting defects that are deeply buried inside the specimen. In this paper, the experiment and simulation were conducted on stainless steel plate 304 fabricated with open surface defects having a different defect depth as an investigation towards the correlation between extracted signal feature and defect depth. Two common features; time to peak and peak value that corresponds to the location depth of defect and size of defect were used for signals analysis and evaluation. The results that acquired through finite element method (FEM) simulation were compared with experimental results for the signals evaluation and defect quantification.

Keywords: Non-destructive testing; pulsed eddy current; finite element method

Pengujian arus pusar denyutan (PEC) merupakan salah satu teknik ujian tanpa musnah (NDT) termaju yang beroperasi berdasarkan kepada prinsip eletromagnetik. Teknik ini mempunyai julat frekuensi yang luas menjadikan teknik ini mempunyai kelebihan untuk mengesan kecacatan yang wujud di dalam specimen. Di dalam kajian ini, eksperimen dan simulasi dijalankan ke atas kepingan stainless steel 304 yang mempunyai kecacatan permukaan dan mempunyai kedalaman yang berbeza. Dua cirian utama iaitu time to peak dan peak value yang mewakili lokasi kecacatan dan saiz kecacatan di gunakan di dalam menganalisa isyarat. Keputusan yang diperolehi melalui eksperimen serta finite elemet method (FEM) dibandingkan.

Katakunci: Ujian tanpa musnah ; arus pusar denyutan ; finite element method

1. INTRODUCTION

Eddy current technique (ECT) is non-contact electromagnetic based Non-Destructive Testing (NDT) method that is widely used in industrial field for the purpose of ensuring the overall safety, integrity and reliability of electrically conductive structures and components. This method has the ability to detect defects occurred at the surface or deeply buried inside the tested material from its interaction with electrically induced eddy currents (1). During the inspection, eddy current is operated based on single frequency sinusoidal excitation and defects are detected as the change in impedance monitored on an impedance plane diagram (2). This conventional method is quite sensitive to variety of parameters that may influence the accuracy of signals detection and evaluation (3). Even though the multi frequency eddy current had been introduced however the drawbacks is in the limitations of its penetration. In contrast to conventional eddy current testing which uses sinusoidal wave, pulsed eddy current (PEC) uses a square waveform to drive the excitations coil.

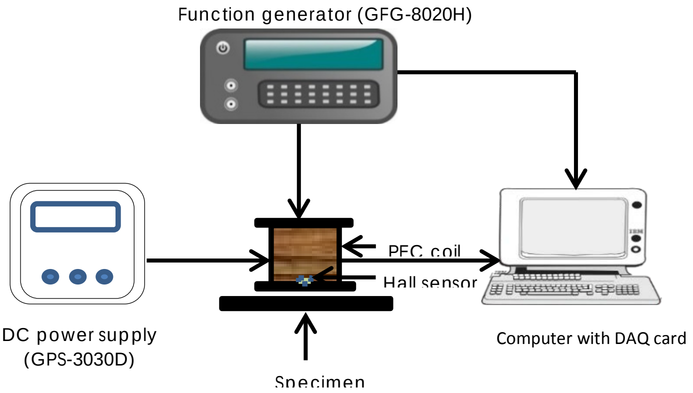
The Fourier transform of a square pulse consist a series of frequency contents in which its excitation allow a deeper eddy current penetration and this provide information about the defects location either at the surface or subsurface of the sample (4). Yunze *et. al* described PEC as higher robustness of anti-interference and also can reduce the power consumption during the operation. (5-8). Due to high demand from industry on the defect quantification including the 3D shape, volumetric losses and pattern recognition, it is essential to establish the linkages between experiment and simulation to facilitates not only forward problem but also inverse solution.

(9)The main objective of this paper is to perform experiment and simulation on different defect depth and to establish the correlation between the signals and features that had been acquired through signals processing and analysis.

2.0 DETAILS OF THE STUDY

2.1 Pulsed eddy current system

Pulsed eddy current system basically is combination from multiple equipment including power supply, function generator, power amplifier and PEC coil as a detector as shown in Figure 1 a and b. Power supply is an electric device that functions to supply voltage value to operate the magnetic sensor. Function generator is operates to generate a different waveform type wide a wide range of frequency. For the signals processing, all the signals detected by the coil will be transferred, displayed and process using the computer completed with data acquisition card. PEC coil are generally robust, small and provide a high sensitivity in detection. In this experiment, the coil was fabricated with an excitation copper wire wounded around the ferrite core with certain number of turns. In order to enhance the sensitivity of detection and empowering the magnetic field concentration a magnetic sensor (Hall SS490) was placed at the centre of the coil as illustrated in Figure 2. For the simulation works the coil has dimension of 16 mm outer diameter, 14 mm inner diameter, 3 mm height and made up from 300 turns of copper wire as shown in Table 1.



1a Schematic diagram of pulsed eddy current system

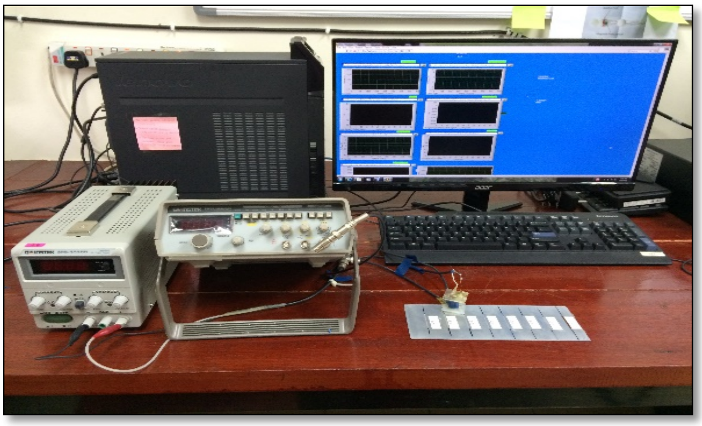


Figure 2b Pulsed eddy current system

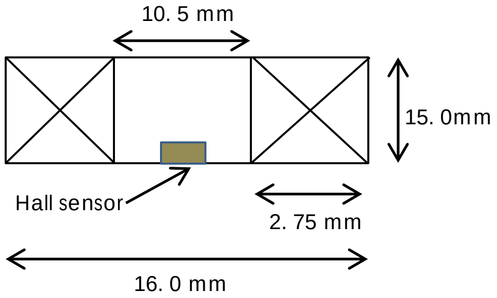


Figure 3 Schematic diagram of PEC coil

For a cylindrical coil located over a metal specimen as shown in Figure 2, the magnetic field in the air in the region of the specimen is given such as in Eq. 1

$$\boldsymbol{B_z} = \boldsymbol{B_Z^c} + \Delta\boldsymbol{B_Z} \qquad (1)$$

Where $\boldsymbol{B_Z^c}$the field is produced by the coil $\Delta\boldsymbol{B_Z}$ and is the field change caused by the specimen.

Table 1 Parameters of the coil

Outside Diameter	Inside Diameter	Coil thickness	Height	Number of turns
16 mm	10. 5 mm	2. 75 mm	15 mm	300

2.2 Simulation Set-Up

The 3D finite element analysis were conducted in transient mode to establish the correlation between the defect depth with the magnetic field in Z direction and the differential magnetic field are calculated as in Eq. 2.

$$\Delta B_{zm} = B_{Zm} - B_{Zref} \qquad (2)$$

where $B_{Zm}$is the magnetic field for surface defect, $B_{Zref}$is the magnetic field for reference signal and *m* represents the defect with different depth = 0.15 mm, 0.20 mm, …, 0.50 mm. In this simulation all the parameters are set equally same as performed while conducting the experiment testing. The simulation is run individually on each defect while the probe is located at the top of defect surface. There were 2 mm distance between the PEC coil and the specimen as to represent the lift off such performed in the real experiment. Figure 3 shows the schematic diagram of simulation orientation for defect depth 0. 15 mm. These simulation processes are repeatable for all the seven defects and the signals acquired are saved for the defect analysis and interpretation using MATLAB. Figure 4 shows the streamline acquired from 0.15 mm depth defect. From the figure it shows that the magnetic fields are dense on the defect and getting lesser once it travels away from the coil centre. Meanwhile Figure 5 shows the external current density on X direction. In this simulation, the X-Y axis is assigned as the direction for the current to flow though. Thus the external current density flow is maxima for both direction and zero in Z direction. The different colour shows the negative and positive polarity represent the current flows through the copper wires.

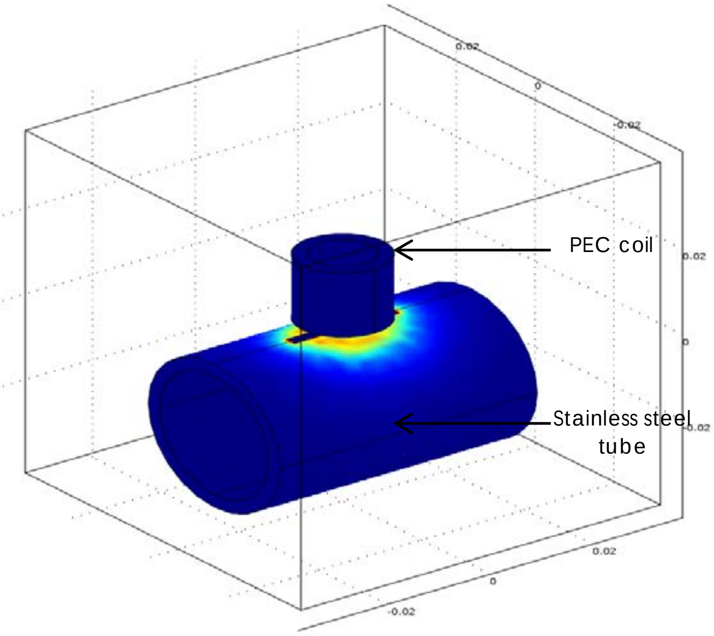


Figure 3 Simulation model of 0. 15 mm defect depth

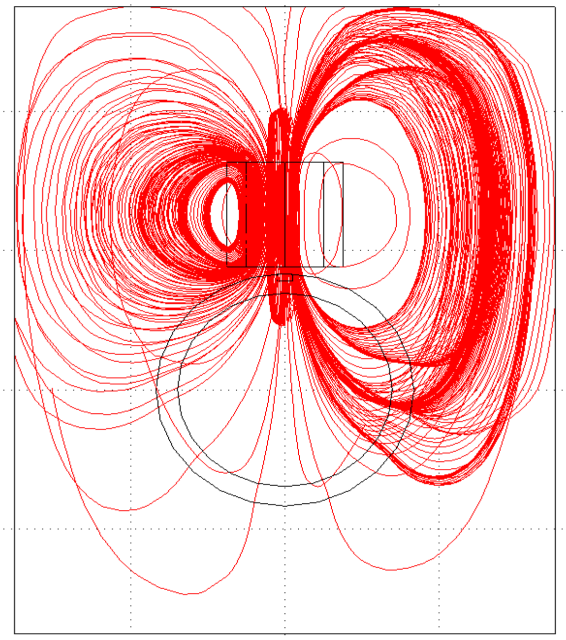


Figure 4 X-Y orientation of magnetic flux density streamline acquired from 0.15 mm depth defect

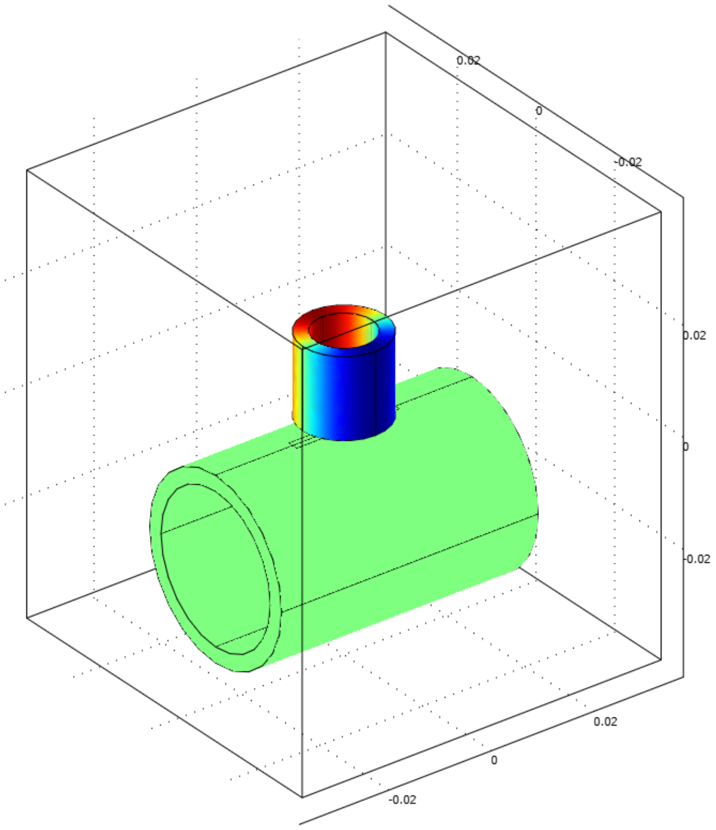


Figure 5 External current density of X-Y poles polarity

3.0 RESULTS AND DISCUSSION

Figure 6 shows the magnetic field acquired from simulation works on 8 different signals with the pulsed width size is 2.5 ms. From the figure it can be described that the signals acquired while the probe is holding in the air has the highest magnetic field followed by 0.50 mm, 0.40 mm, 0. 35 mm, 0.30 mm, 0.25 mm, 0.20 mm, and 0.15 mm defect respectively. The established relationship shows that the magnetic field value is directly proportional with increasing of specimen volumetric losses. In this case, the second highest magnetic field was acquired from 0. 50 mm defect depth that represent hole due to relatively almost zero of total eddy current opposition that exists inside the specimen. Theoretically, the PEC coil that excited by a rectangular pulse generates eddy current inside the stainless steel plate. The total eddy current strength is influence based on remaining specimen thickness as the thicker specimen having a highest eddy current density.

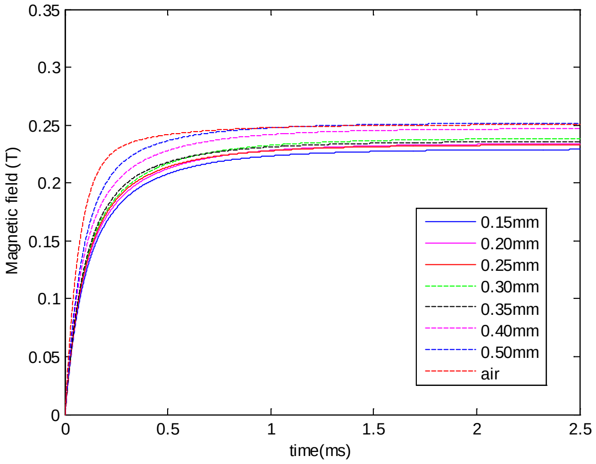


Figure 6 Time domain transient response of 8 different signals acquired from simulation work

The signals acquired while probe is holding in the air are assigned as a reference signals. Thus to obtain a differential signal, each defective signal is subtracted to the air signal. Fig 7 from simulation works on various defect depths with the highest magnetic field are acquired from 0.15 mm and followed by 0.20 mm, 0.25 mm, 0.30 mm, 0.35 mm, 0. 40 mm and 0.50mm defect depth respectively. Since the specimen has a same opening width and representing the surface defect thus the time to peak of each defect supposed to be happened at the same time because the magnetic field is travel in the air with conductivity value 1 (6). Meanwhile the peak value of each defect is inversely proportional with the depth thickness. As described by Tian *et. al (11)* time to peak generally corresponds to the location depth of the defect. Table 2 shows the time to peak and peak value for different defect depth.

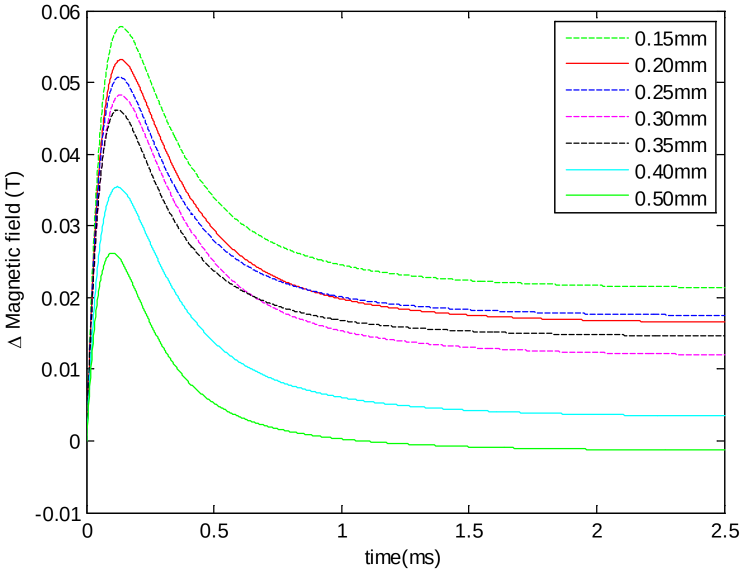


Figure 6 Differential signals from different defects depth from experiment

Table 2 Time to peak and peak value for multiple defect depth

Depth (mm)	Time to peak (ms)	Peak value (T)
0.15	0.54	0.1840
0.20	0.55	0.1800
0.25	0.55	0.1570
0.30	0.55	0.1460
0.35	0.55	0.1270
0.40	0.55	0.0111
0.50	0.55	0.0100

3.0 CONCLUSION

This paper has reported the capability of PEC technique in detecting the surface defect on stainless steel 304 tube. Based on the results obtained through simulation works, it has been proven that the peak value and time to peak for different defect depth are associated with the volumetric losses including thickness, size and location of the defect. For the defect detection, the fabricated probe has a high sensitivity in detecting and ability to distinguish a defect with 0.05 thicknesses different. The signals acquired from simulation by FEM had shown a similarity with the experimental signals and this would be solution in solving a forward and reverse problems.

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