The Evaluation of Pulsed Eddy Current Technique for Detection and Characterization of Surface Defect in Carbon Steel Welded Sample: An Experimental Study

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Article Info

Abstract

Pulsed Eddy Current (PEC) is an advanced Non-Destructive Testing (NDT) method based on the principles of electromagnetic induction which generate square wave form. This study was carried out to investigate the surface defect that occurs in carbon steel welded sample (ASTM A36) and to investigate the signal profile of a transverse crack orientation with different defect depths which are 1mm, 2m, 3mm, 4mm and 5mm. A total of five test samples have been used to execute this study with different defect depths. MATLAB is used to generate the result and from the result, it shows that transverse crack is inversely proportional where the deeper the crack, the lower the magnetic field where the magnetic field dropped by 3.54% from 1mm to 2mm of defect depths. However, 3mm of defect depth decreased by 5.55% when compared to 2mm. Meanwhile, with defect depths of 4mm and 5mm, each magnetic field reduced by 2.59% and 4.91%, respectively. This is due to the changes of relative permeability and electrical conductivity of the test sample after welding process been done and affected the magnetic field that acquired. Therefore, it shows that PEC is an effective method of NDT in order to detect the surface defect carbon steel.

1. Introduction

Nowadays, carbon steel is one of the most common materials that been widely used in the industries [1]. The production of nuclear energy, the medium connection of oil and gas pipelines, the manufacture of machinery, and transportation all made extensive use of carbon steel components. Most of the time, carbon steel plates were utilised for welding as parts of pressure-bearing machinery [2]. Welded joints are being used in crucial components where failures are disastrous [3]. Carbon steel welds frequently contain fractures, corrosion, porosity, and other problems because of prolonged high temperature, high pressure, causticity, and other undesirable changes in the working environment [2]. This causes early equipment degradation and may even endanger human life. Consequently, it is essential to regularly do the inspection at the welded area for the carbon steel material to avoid any disastrous consequence that might occur.

The inspection on carbon steel material by using Pulsed Eddy Current (PEC) is not given much attention on detecting the defect at the surface and subsurface area of the plate for ferromagnetic material because most of the PEC testing research that has already been published thus far has focused on the non-ferromagnetic materials [4]. According to other researchers, PEC testing is a new eddy current NDT technique under development [5]. PEC has a greater frequency range than Eddy Current Testing (ECT), which has a single frequency [5]. Also, the signals obtained during PEC testing are straightforward to understand. Standard ECT only employs a single frequency for stimulation, rendering it ineffectual in identifying both surface and subsurface problems [5]. Yet, PEC testing technology is a subset of ECT testing technology [6]. Yet, its detection depth is larger than ECT testing technology, and a scan may complete the detection of a large area of a complex structure, offering a reliable assurance of automated detection realisation [6]. Compared to conventional eddy current method which gave single frequency and sinusoidal wave, PEC, on the other hand, to drive the excitation coil, it uses the square wave form which allow the eddy current to penetrate deeper within a shorter time [7].

2. Methods

For this study, a structural carbon steel plate according to code and standard of ASTM A36 (EN S275) was a material used as the specimen for the experimental work. This plate was cut into the dimension of $250mmL \times 200mmW \times 7mmT$ and was fused to form a single butt weld joint by using Gas Tungsten Arc Weld (GTAW) method. A rectangular notch which was in transverse direction with dimension of $0.7mmW \times 25mmL$ was created by using the Electrical Discharge Machining (EDM) method due to it parameter where each specimens having different depth of the defect which were 1mm, 2mm, 3mm, 4mm, and 5mm as shown in Fig. 1(b). Five test samples with rectangular notch with the depth of defect varies amongst samples were created.
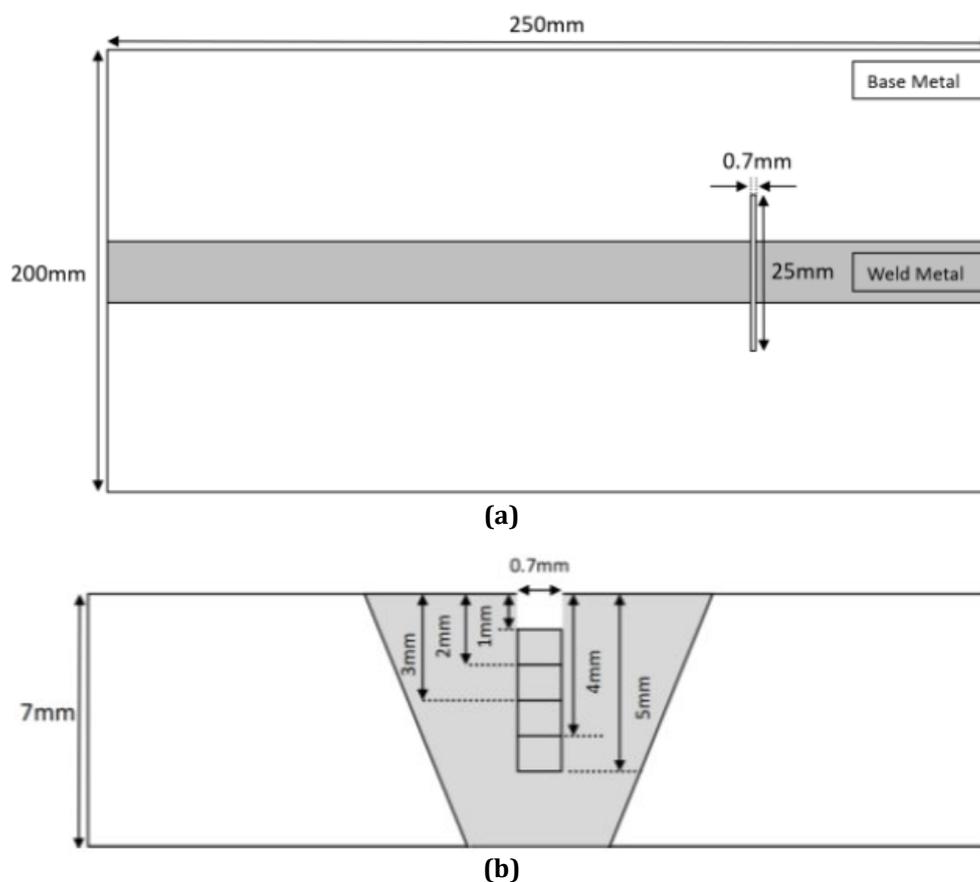

(a)

(b)

Fig. 1 *Schematic drawing of test sample (a) The direction of orientation; (b) The depths of defect (drawing is not to scale)*

To guarantee that there was no more lift-off throughout the process of carrying out the experimental work for this study, "A" where it was the welded region or welded bead that had been removed by utilizing grinding activity, as depicted in Fig. 2, was utilized.

Fig. 2 *Test sample after grinding activity*

2.1 Experimental Set Up

The experimental set-up used for this study consists of DC power supply, function generator, a probe and PC monitor as shown in Figure 3.
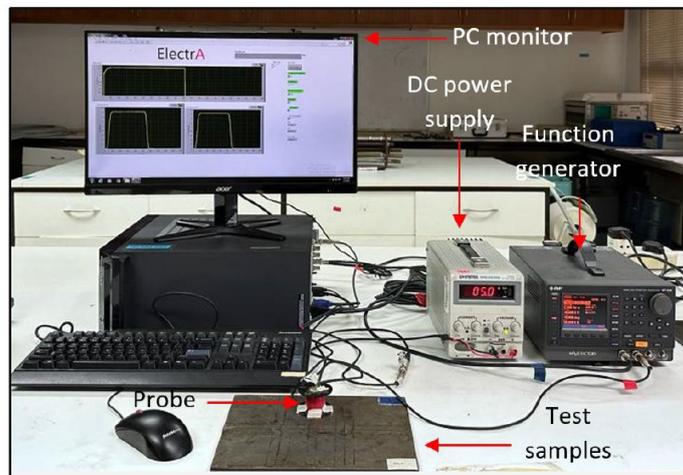

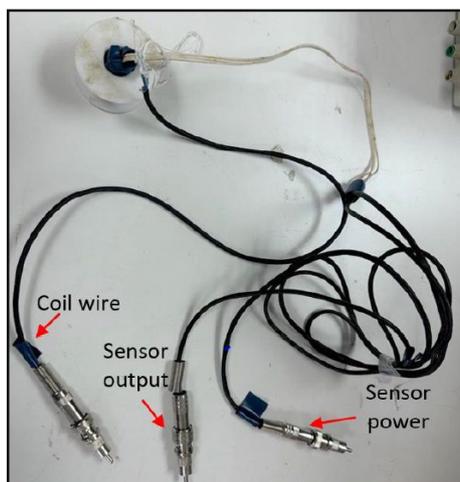
Fig. 3 *PEC system*

Fig. 4 *Completed probe connection*

The developed PEC probe's transient magnetic field responses are critical to the investigation. As a result, it was vital to double-check that the PEC probe is correctly attached before starting with the testing; otherwise, the Data Acquisition card (DAQ) would not receive any signal from the PEC probe due to a connection issue. The PEC probe had linked to three cables: a 'Coil Wire', a 'Sensor Power' cable, and a 'Sensor Output' cable as shown in Figure 4. The 'Coil Wire' should be connected to the function generator, the 'Sensor Power' cable should be connected to the DC power source, and the 'Sensor Output' wire should be connected to the computer.

The behaviour of the generated eddy currents in the test material is consequently determined by the properties of the current that flows through the coil because of these waveforms. The frequency was set to 100Hz. NF WF 1948 was the model of the function generator used for this study. The Hall sensor, a crucial part of the PEC system, was powered by the DC power supply with 5V of voltage been set. Table 1 shows the coil's features that had been used for this study.

Table 1 *Feature of PEC probe*

Outside Diameter, OD (mm)	Inside Diameter, ID (mm)	Thickness (mm)	Lift-off (mm)	Height (mm)	Number of Turns
21.8	17	0.4	2	25	300

After done with the experimental setup, PEC testing was performed afterwards to investigate and collect the data and result of the defect appears that been obtained from the experimental activities. A fundamental PEC system has been developed, which consists of three main parts: an excitation source that creates an electromagnetic field in the sample being tested, sensing modules that measure the electromagnetic field, and signal conditioning and processing units that analyse the data and provide useful results for the experiment.

For this study, five carbon steel welded samples with different depth defect and rectangular notch orientation were used to perform the experimental work to investigate the signal of magnetic field obtained from the PEC. The investigation done at the centre of the welded of each sample with different orientation and depth of the defect as shown in Figure 5 where the position of the Hall sensor located at the centre of the welded area that had the defect on it. The notch utilised in the experiment was particularly designed to mimic the presence of defects at different depths inside a sample.
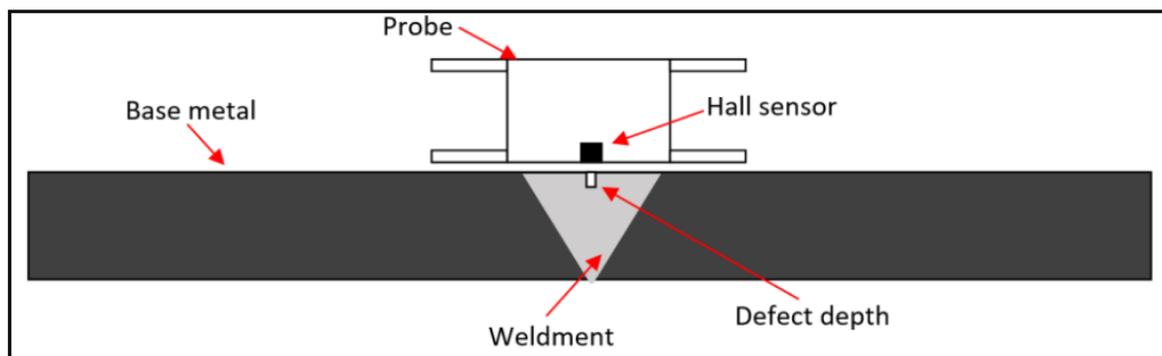

Fig. 5 *Position of PEC probe*

2.2 Data Analysis

During PEC testing, the response or pattern of the measured signal as it unfolds over the period is referred to as the signal profile. There is a possibility that this term is referring to the signal itself that is being monitored. During the portion of the inspection that is dedicated to PEC testing, this will take place. This provides details about how the eddy current signal changes as the probe engages with the object being tested, which is particularly important in situations in which the thing being examined contains flaws or anomalies in it. The experimental investigation used rectangular notch, especially transverse cracks, to examine the detection and characterization of surface defects. The study also aimed to provide a comprehensive understanding of how the orientation of surface defects can impact their detectability and characterization with different defect depths.

Following the completion of the specimen's experimental work, the data must be analysed. Data analysis entails thoroughly inspecting and evaluating the data gathered throughout the experiment to draw useful insights and conclusions. Many statistical and analytical tools, such as charting, computations, and statistical tests, may be used to examine data and identify patterns, trends, or correlations. To ensure the validity and dependability of the

study conclusions, the data must be carefully and completely analysed. The findings of the data analysis provide insight into the topic under investigation, contribute to the body of scientific knowledge, and may point the way toward new avenues of research or practical applications in the future. The MATLAB program was used in this study to analyse and assess the data that was created from the experimental work. The data received from the ElectrA software was used to plot the time-domain response because there were up to 1001 data points.

3. Result and Discussion

The specific shape and characteristics of the signal profile during PEC testing might change based on a variety of factors. These factors include the instrument's setup, the probe's construction, the material's characteristics, and the kind and extent of the flaws that are being found. Specialized expertise and acquaintance with PEC concepts, data processing techniques, and the categorization of flaws are required for the interpretation and analysis of the signal profile. As the excitation signal, the PEC system generates a short electrical pulse. The system is what causes this pulse. This pulse is often transmitted via a coil or probe, which induces eddy currents in the conductive material under investigation.

PEC testing was carried out on the welded area of the carbon steel plate that was located above the rectangular EDM notch, which served as the primary purpose of this research. It is a problem to complete the defect characterization on the test specimen that contains a weldment because the specimen consists of three areas: the Base Metal (BM), the Weld Metal (WM), and the Heat Affected Zone (HAZ). Figure 6 shows the signal profile of differential normalisation Magnetic Field (MF) of each defect depths for the transverse crack orientation of the butt-welding seam. It shows that 1mm of defects that has the highest signal profile of normalised differential MF followed by 2mm, 3mm, 4mm and 5mm of defect depths. The correlation between the two variables reveals that the intensity of the magnetic field is exactly proportionate to the volumetric reduction of the specimens. It shows that the higher the metal loss of the test specimen, the lower the MF signal profile for transverse orientation of EDM notches at weldment.
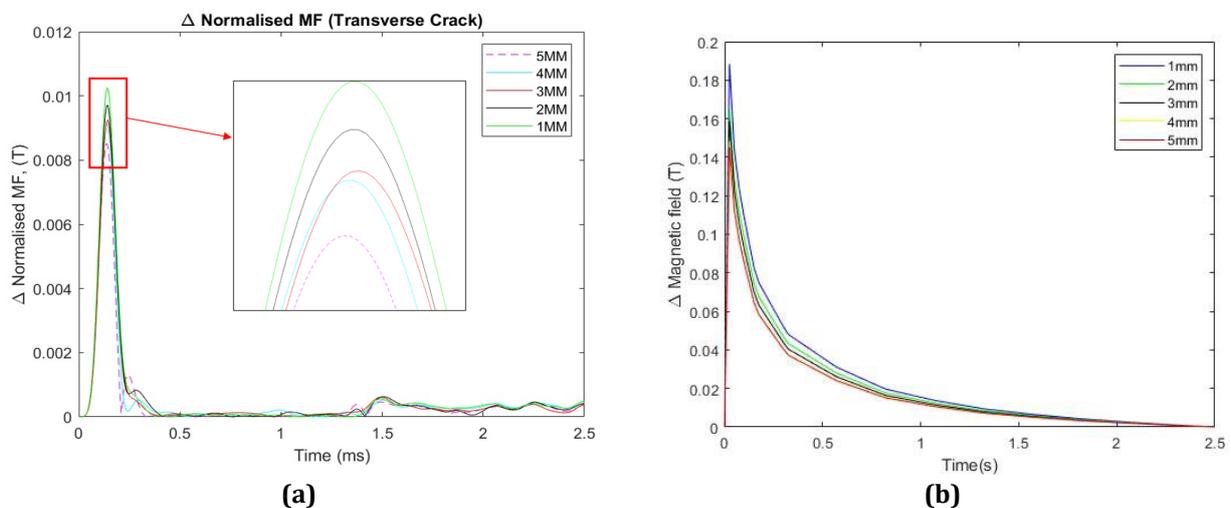

(a)   **(b)**

Fig. 6 *Normalised MF (a) Experimental; (b) Simulation*

The result of MF acquired from the experimental finding as shown in Figure 6(a) has been validated with the finding from the simulation of previous study that done through COMSOL as shown in Figure 6(b) for transverse crack orientation. It has proven that the trend of MF from experimental work and simulation work shows the same trend where the deeper the depth of the defect, the lower the MF amplitude. Despite of having same trend of result from both work (simulation and experimental), it is clearly shows that experimental study shows a disturbance of the signal profile. This was due to the noise that occurred during execution the experiment work. Apart from that, the test specimen will be having vibrations due to the excitation frequency had set as fixed value which will influence the detection sensitivity [8]. For this study, a fixed value of excitation frequency had been used which was 100Hz which cause the disturbance of the signal profile due to the vibration occurred.

Transverse crack is having relationship of inversely proportional where the value of MF is decreasing when the cracks getting deeper. The transmitted magnetic field is mostly impacted by the low-frequency component, whereas the reflected magnetic field is primarily impacted because of the high frequency component, corresponding to the electromagnetic wave transmission theory. As the depth increases, the response signal weakens because of the interaction between the magnetic field that is being sent and the magnetic field that is being reflected [8]. As a direct consequence of this, the amplitude of the response signal decreases as the depth of

the defects increases. Referring to Table 2, it shows that 2mm of defect depth decreased by 3.54% of MF from 1mm defect depth. But 3mm of defect depth on the other hand, decreased by 5.55% compared to 2mm. Meanwhile, for 4mm and 5mm of defect depths each MF decreased by 2.59% and 4.91%, respectively.

Table 2 *Value of MF with different defect depths*

Defect Depth (mm)	Magnetic Field (T)
1	0.10676
2	0.10298
3	0.09726
4	0.09474
5	0.09009

The frequency of the eddy current probe, the magnetic permeability of the specimen, and the conductivity of the specimen all influence the probe's response [9]. Both the specimen's magnetic permeability and its electrical conductivity are determined by the microstructure of the material and any changes occurred in the magnetic permeability of the test specimens or sample have an impact on the signal produced by the probe [10]. The electrical conductivity is decreasing which opposed with the gradient value of relative permeability where it is increasing from the weldment toward the Base Metal (BM) [9]. Meanwhile for transverse crack defect orientation, it is clearly shows during the testing the defects across three areas which were the WM, HAZ and the BM. At these three areas, the value of the electrical conductivity as well as the relative permeability are different which is the main reason of why the MF for transverse orientation is lower.

4. Conclusion

As conclusion, PEC has the ability and effective in detection of surface defect in carbon steel material. To validate the result acquired, the result from experimental work for this study has been compared to simulation work that been done previously by other researchers. It shows that the result obtained from the simulation done using COMSOL has proven that the experimental and simulation work give the same trend of magnitude field amplitude. It shows that for transverse crack is having the relationship of inversely proportional toward the defect depths. However, for experimental the signal profile of the magnitude failed shows the disturbance which cause by the noise. Therefore, the signal profile of the magnitude field for each defect orientation with different defect depths differ towards each other because of the changes of the magnetic permeability of the material especially for transverse crack orientation where the orientation across three materials permeability. This phenomenon contributes to the different signal profile obtained during performing the experimental study.

Acknowledgement

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Author Eliza M. Yusup, Author Nurul A'in Ahmad Latif; **data collection:** Author Lizawati Salleh; **analysis and interpretation of results:** Author Lizawati Salleh, Author Nurul A'in Ahmad Latif, Author Ilham Mukriz Zainal Abidin; **draft manuscript preparation:** Author Lizawati Salleh, Author Eliza M. Yusup. All authors reviewed the results and approved the final version of the manuscript.*

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