Differential Pulsed eddy current probe to detect the sub surface Cracks in a Stainless Steel Pipe

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Abstract
In the present study a differential probe for the pulsed eddy current (PEC) has been fabricated to detect the sub surface cracks of thick plate. The tested sample is a SS304 of thickness 5mm; small electromagnetic discharge (EDM) notches were machined in the test sample at different depths from the surface to simulate the sub surface cracks in a pipe. The PEC probe has two excitation coils and two detecting Hall-sensors. The difference of two sensors is the resultant PEC signal. The cracks under the surface were detected using peak amplitude of detected pulse; in addition for the clear understanding of the crack depth, the Fourier transform is applied. In the time domain the peak amplitude of the detected pulse is decreased and in frequency domain the magnitude of low frequency component has been increased with increasing the crack depth. The experimental results have indicated that the proposed differential probe has the potential to detect the sub surface cracks in a stainless steel structure.

Keywords: Sub-surface cracks, pulsed eddy current, peak amplitude, Fourier transform

1. Introduction

Nondestructive testing (NDT) of the steel structures for the identification of sub-surface cracks has always been great industrial interest. The cracks and defects are real threat for reliability of a structure, as they can rapidly grow to cause failures of structural integrity, to prevent these failures nondestructive testing (NDT) is used as a predictive approach to maintain the safety of the structures [1]. The PEC testing is one of the most effective methods, which has been demonstrated to be capable of tackling different inspection tasks, such as sub-surface defect detection in complex structures [2-4]. Among the available conventional NDT methods, one of the most used is eddy current testing (ECT) to detect the flaws in conductive materials [5, 6]. The conventional ECT uses the single frequency sinusoidal excitation for the detection of the defects or flaws as a function of change in voltage, impedance or phase, because of limited depths of penetration and complexity in signal analysis ECT was confined to limited applications [7]. Unlike conventional ECT the PEC uses pulse of electric current through the excitation coil. Because of many advantages of PEC over the conventional eddy current method, such as low power consumption due to the short pulse excitation, this method more is economical than other NDT methods. Because of broad band nature a pulse PEC has the capability to penetrate different depths in a conductive material and provides the depth information of the defects [8, 9]. Even though the use of PEC has long been considered for the testing of materials [10, 11], the PEC testing becomes the subject of wide spread interest in nondestructive testing in recent decades, because of advancement of technology such as computer data acquisition and digital signal processing. The PEC has the capability such as measurement of thickens, conductivity and has been particularly developed for sub-surface crack measurements, crack reconstruction, and depth estimation [12-14].

In the present study a double-D differential probe has been developed, Usually in the PEC a reference signal has to be taken before measurements [15] for the difference process (reference signal subtracted forms the measured signal). The double-D probe has self
difference characteristics; hence reference signal is no longer needed. The paper is arranged as follows; firstly the experimental setup, probe design and testing sample were given in section 2. The experimental results with scanning of test specimen and signal processing were included in section 3. Finally, section 4 followed by conclusions.

2. Experimental Setup and PEC Probe

The PEC system has an arbitrary waveform generator, a power amplifier to amplify the pulse and drive the excitation coil in the PEC probe, a differential PEC amplifier, and a data acquisition system as shown in Figure 1 (a). The configuration of probe is as shown in figure 1(b), the core of the probe is fabricated by two semi circular shaped cylinder cores were joined together to form a double-D shaped core, the copper wire of 100 turns has been wound on both the D-shapes of the core and both the coils were connected in series. Two Hall sensors were placed inside center of the each coil, to get the field from the coils, difference of the field which detected by the sensors is used as the resultant PEC signal. The tested sample is a SS304 steel of 5mm thickness, 80 mm width and 220mm length. To simulate the cracks in steel pipe, small EDM cracks having the width of 0.2mm and length of 20mm at different depths 1, 1.5, 2, 2.5mm (crack1, 2, 3, 4 respectively) from the sample surface (probe position) were machined one side of the sample. During the PEC measurements the probe has been place on the opposite side of crack surface to detect the sub-surface defects in the tested sample. The PEC probe is fixed to the X-Y scanner to perform the manual scanning on the defect free side of the tested sample. A Lab VIEW based data acquisition program was developed to continuously monitor the variation in the thickness of the sample and is observed on the computer screen. The time domain feature which is the peak value of detected pulse is used for the scanning test to detect the sub-surface cracks in the stainless steel tested sample.

![Figure 1. (a) configuration of PEC system, and (b) design of the double-D differential probe](image)

Briefly, the PEC system works as follows; a rectangular waveform with variable frequency and duty cycle produced by an arbitrary waveform generator. The waveform is fed to a pulse amplifier to drive the excitation induction coil in the probe. The pickup sensors (Hall-1, Hall-2) will measure the vertical resultant magnetic field, which is the vector sum of the field one generated by the excitation coil and the opposing one generated by the induced eddy current in the sample. The outputs of Hall-1 and Hall-2 were given to a difference PEC amplifier with variable gain then the difference of two detecting sensors is used as PEC signal.

3. Experimental results and feature extraction
As shown in Figure 1 the PEC probe has two excitation coils are wounded opposite to each other on a ferrite core and are connected electrically in series. The excitation coil has been driven by a 2A, 2.5ms pulse with 50Hz repetition rate. When the probe is driven by a pulse, field detected by the Hall-sensor 1 (Hall-1) and the Hall-sensor 2 (Hall-2) and the difference signal were shown in Figure. 2, here the response from both sensors is almost same.

Figure 2. The response of two Hall sensors and the corresponding difference pulse when the probe is excited by a pulse width of 2.5 ms

As the sensors detects the sum of excitation field and induced eddy current filed, technically we can understand that, because of the differential arrangement of two sensors the excitation field is nullified, hence only the induced eddy current fields were detected. If the probe placed on the sample in such a position that one of the Hall-sensor comes above the crack and other sensor on defect free position. Then the detected differential pulse is of interest to interpret the results, the important characteristic is the peak value of the pulse. As shown in figure. 3, the detected pulse amplitude is decreased with increasing the crack depth, because if the crack is nearer to the surface of the sample (higher volume of crack or higher metal loss) that means there is large difference of conductive area present under the two Hall-sensors hence the differential pulse amplitude is high, but if the crack is far from the sensor (lower volume of crack or lower metal loss) then the conductive area present under the two sensors is
almost same so the difference pulse is peak is less. There are several signal processing methods can be applied to analysis the PEC signal [16], here in the present study the Fourier transform of the pulse has been devised. The results shows that the FFT of the PEC response for the crack nearer to the surface has the small value of lower frequency component but dominates in the higher frequency region, and response for the crack at larger depth has dominant response in lower frequency range.

Figure 4. The FFT of the Pulsed Eddy Current response to the crack depending the depth

Since the detected pulse consists of a broad frequency spectrum, it contains the important depth information, physically, the field is weakened as it travels deeper in to the highly dispersive material [17]. In other way because of broad band nature of the PEC, the greater amount frequencies in a pulse return the affluent information at many depths of test sample; according to skin depth relation lower frequency components can penetrate more depth in to the sample, the test sample acts like a frequency filter [18]. Figure 5 shows the scanning results of tested sample, during the scan the probe has been placed on the defect free side of the sample, the measurement feature for the scanning test is the peak amplitude of the detected pulse.

Figure 5. The scanning results of PEC probe scanned on the defect free side of the test sample
4. Conclusions

The nondestructive evaluation (NDE) method to detect the sub-surface crack using PEC under the thick stainless plate has been devised. A differential probe which is used in PEC system has been fabricated for the detection of sub-surface cracks in stainless steel type SS304 pipe. The EDM notch of length 25, width 0.2 and depth 1 to 2.5 mm from the probe surface were detected using specially designed double-D differential PEC probe. The amplitude of the signal induced by crack is decreasing as the distance from the probe to crack increases. The time domain features of detected pulse such as pulse amplitude was used to detect the cracks. The signal processing techniques such as Fourier transform for the detected pulse was derived to analyze and understand the PEC results. These parameters are well described the sub-surface crack. The scanning results were successfully displayed on the computer monitor. The results show the proposed differential PEC technique has the potential to detect the minute subsurface cracks in pipelines.

References