Multi-Excitation Signal for Depth Crack Defect in Eddy Current Testing

Kharudin Ali[1,2,*], *Ahmed* N Abd Alla[1], *Radin* Muhamad Amin[1], *Damhuji* Rifai[1] , *Moneer* A Faraj[1]

[1]Faculty of Engineering Technology, University Malaysia Pahang, Malaysia
[2] Faculty of Electrical and Automation Engineering Technology, TATI University College, Kemaman, Terengganu

Abstract. Eddy current Non Destructive Evaluation (NDE) is one of the more commonly used techniques in measure electrical conductivity and thickness of plate and pipes. In recent years, several works have reported the sensitivity of probe in measuring the depth of crack according the input excitation. To extract relevant features for input excitation types of waveform, range frequency and depth of crack have been proposed. In this paper, a method to getting clear signal output for crack detection and data for differential depth of crack identified is reported. The measuring method Mulit-Excitation Signal (MES) is based on ac current signal, pulse signal and triangle signal. A frequency signal is set from 10KHz until higher 90KHz by following the probe's limitation. Otherwise the calibration block is used as a defect plate with the depth of crack is 0.5mm, 1mm and 1.5mm. As a result the depth of cracks signal were clearly shown by using the three types of waveform with different levels of frequency and could be concluded when frequency of input excitation is high then the ability of signal to measure the crack on the material will decrease and if frequency is low then travelling signal in defect measuring is high but the responses time is low.

1 Introduction

Nondestructive evaluation (NDE) deals with the inspection of an object for determining its properties without destroying its usefulness. Applications include detection of cracking in aircraft, nuclear, coating industries, steam generator tubing in nuclear power plants, aircrafts, etc (1). Eddy current NDE is one of the more commonly used techniques. The eddy current method can be applied to measure electrical conductivity and thickness of thin coatings on metallic material.

Modern marches on in SQUID (2) and Pulsed Eddy Current (PEC) (3)(4)(5) have been describe in the literature constructing eddy current testing more appealing in quality control and inspecting area (6)(7)(8)(9). Michael Faraday's discovery of electromagnetic inductance in 1831 opened the possibility to develop eddy current testing instrumentation. Hughes in 1879 was the 1st individual to implement eddy current testing (10). He showed changes in the attributes of a coil while graded in reach with metals of dissimilar conduction and permeableness. Respectable work was done in the 1950's and 1960's in developing of the hypothesis and experimentations with eddy currents. Eddy current techniques are largely applied for two characters of applications. One is to notice fault and inspect the circumstance of samplings (11)(12)(13). The consideration of samples perhaps associated the surface-cracks, submerged flaw and degradation of samplings (14). As this kind of application, the nature of the fault must be considerably realised appropriate to find effective inspection results. Since eddy currents tend to concentrate at the surface of a sample, they could only be accustomed detect defects approximately the surface. Another important application of eddy current testing is to evaluate the properties of samplings, including the electric conduction (15), magnetic permeableness (16)(17) and thickness of samples by according the excitation signal(18). The excitation signals are usually uses in industry are AC and Pulse.

Various sinusoidal tone combined to produce a multi-frequency signal, which aims to increase the frequency component as desired by the desired amplitude (19)(20). A low-frequency eddy current method used to estimate internal deep defects in ferromagnetic material and iron plate (21). (22) One of the methods in Eddy Current Testing (ECT) uses a single coil both for excitation and detection. In this case, changes in coil impedance are used in detecting the presence of conductive materials. ECS has been designed and developed based on multiple frequencies to measure cracks in metal structures (23)(1). This includes the peak AC source and remains capable of operating in the frequency range for the metal surface and sub-surface near the crack metal.

The ECT signal is to simulate the pulses on the procedure Frequency Domain Summation (FDS) is as follows. Then, a sinusoidal wave signal in response excitation pulses signal which is the difference of the harmonic frequencies as their use (24). Phase direct current DC characterization stable segment is proportional to the magnetic permeability of the material under a test. PEC response to the transient segment is determined by the time constant, which has a complex dependence on both the electrical conductivity and magnetic permeability in the test piece. Although the changes in the magnetic permeability may be weak, the EC changes in the steel for cold work, because they are stronger than non-ferrous materials (25).

In this particular study, the main focus is on input excitation signal which includes AC signal, Pulse signal and Rectangular signal for Differential probe. The effect of excitation signal in crack measuring due to the depth

* Corresponding author: kharudin@tatiuc.edu.my

travelling on the plate or pipe inspection is identified besides of clarity output signal derived.

2 Process Developments

2.1 Probe Drive Circuit Development

In schematic circuit there are five important parts that should have in ensuring the system is properly functioning. The first part is input excitation supplies (IES) that functioning to supply the voltage for absolute probe and differential probes. In here the function generator was used with according the frequency selecting and setting. Second part is probe application. The types of probes used are absolute probe and differential probes. The concept probe is air-coil probe sensor that generates the magnetic field when the IES through it. When the defects are occurs on the test plate then the signal reading will be show the different. The third part is output devices that function as indicator and displaying the depth defect on the work piece. From here the LCD and buzzer was used. Second last part is controller devices. In this system the Arduino Mega 2650 is used as a data processing receiving and transmitting. The fasting speed for controller is 16 bit data processing and appropriate on this system. The last part is PC interfacing. From here the MATLAB 2015 is used as a signal analysis and intelligent application on this project. From here the filtering signal, fuzzy logic application and output waveform of each defect will be show on the monitor. The connection between PC and microcontroller is using serial communication interfacing. Fig. 1 shows the design of driver circuit for probes connection, microcontroller and PC interfacing.

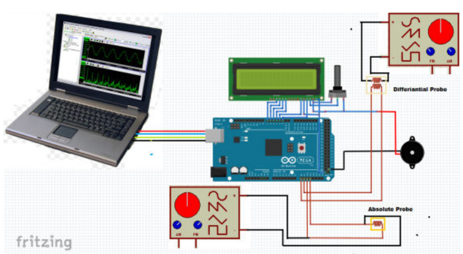


Fig. 1: Probe Drive Circuit

2.2 Hardware Development

Hardware constructed is shown in Fig. 2 by based on the schematic circuit in Fig. 1. The hardware consists of Arduino Mega 2650 with function generator connection with the probes. The input, processing and output used including the absolute probe and differential probe, buzzer, LCD display and PC with MATLAB 2015 software. The Arduino Mega 2650 that have been embedded in programming C language is connected with PC with MATLAB 2015 software. The differential probe is connected to pin A0 and A1 of Ardiuno. The output voltage from the absolute probe has been the input of Arduino and connected with A2 and A3 pin for Arduino. After compensation, the LCD display will shows the depth of crack from probes measuring at work piece and buzzer will be sound when defect is identify.

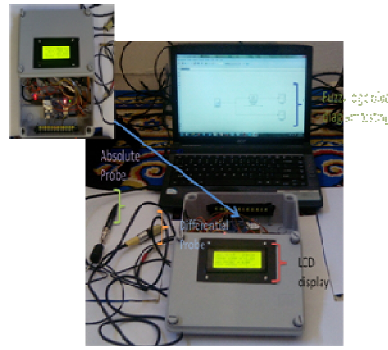


Fig. 2: Hardware of Difference Excitation Signal Scheme

2.3 Probe Shoes Design Development

Probe shoes are very important in integrating probes. The designing of probe shoes should being match with absolute probe and differential probe combination. From here the right sizing, diameter, and orientation must be considering. By following the Fig. 3 the length of probe shoes is 25mm with the diameter probe is 12mm. The gap between probes is only 1mm.

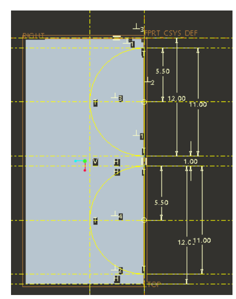
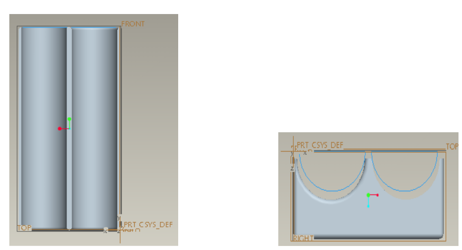
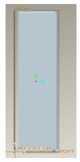


Fig. 3: Dimensioning of Eddy Current Shoes

Dimensions of probe shoes are show on Fig. 4. From here the three dimensions are shown with respectively of front view, top view, and side view. The height of probe shoes is lower than probes. It to ensure the probe points touch the plate or pipe when inspection is conducted. According of this design, the height of probe shoes is 68mm.



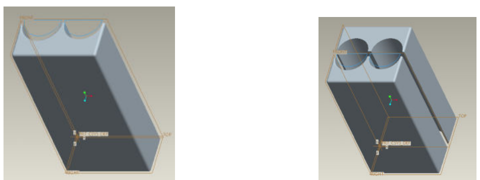
(a) (b)



(c)

Fig.4: The view of Eddy Current Shoes (a) Front View, (b) Top View, (c) Side View

Standard orientation for probe shoes is show in Fig. 5 (a) and (b). From here the both probes will be clamp on probe shoes. To ensure the result will be getting are accurately, the orientation of probe should be right and the points touching probe should in same level in each other.



(a) (b)

Fig. 5: (a) Standard Orientation Half Shoes, (b) Standard Orientation Complete Shoes

3 Characterization Input Waveform

3.1 AC Waveform

An alternate operate or AC Waveform then again is characterised as one that changes in both magnitude and way in approximately an even mode on regard to time getting in a "duplex" waveform. An AC function can correspond either a power source or a signal source with the conformation of an AC waveform commonly keeping up that of a mathematical sine curve as delimited by:

$$- A(t) = Amax \ x \sin (2\pi f t) \qquad (1)$$

The characterizing of AC Waveform can be identifying according three factors there are:

• The Period, (T) is the length time in seconds that the waveform takes to repeat itself from start to finish. This can also be called the Periodic Time of the waveform for sine waves, or the Pulse Width for square waves.

• The Frequency, (f) is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($f = 1/T$) with the unit of frequency being the Hertz, (Hz).

• The Amplitude (A) is the magnitude or intensity of the signal waveform measured in volts or amps.

Figure 6 shown an AC waveform signal with the 10.29 kHz frequency and 2.5Vpp amplitude for input excitation signal.

Fig. 6 shown the input signal for ac waveform was applied on differential probe.

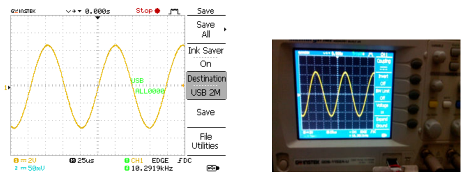


Fig. 6: AC Waveform

3.2. Triangle Waveform

Triangular Waveforms are generally bi-directional non-sinusoidal waveforms that oscillate between a positive and a negative peak value. Although called a triangular waveform, the triangular wave is actually more of a symmetrical linear ramp waveform because it is simply a slow rising and falling voltage signal at a constant frequency or rate. The rate at which the voltage changes between each ramp direction is equal during both halves of the cycle as shown below. Generally, for Triangular Waveforms the positive-going ramp or slope (rise), is of the same time duration as the negative-going ramp (decay) giving the triangular waveform a 50% duty cycle. Then any given voltage amplitude, the frequency of the waveform will determine the average voltage level of the wave. Fig. 7 shown the input signal for triangle waveform was applied on differential probe.

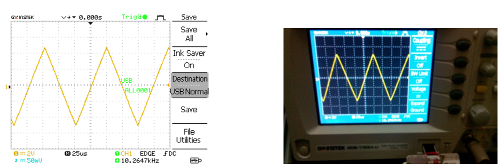


Fig. 7: Triangle Waveform

3.3. Pulse Waveform

A Pulse Waveform or "Pulse-train" as they are more commonly called is a type of non-sinusoidal waveform that is similar to the Rectangular waveform we looked at earlier. The difference being that the exact shape of the pulse is determined by the "Mark-to-Space" ratio of the period and for a pulse or trigger waveform the Mark portion of the wave is very short with a rapid rise and decay shape as shown below. A Pulse is a waveform or signal in its own right. It has very different Mark-to-Space ratio compared to a high frequency square wave clock signal or even a rectangular waveform. Fig. 8 shown the pulse signal waveform was applying at differential probe.

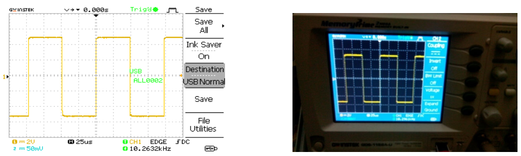
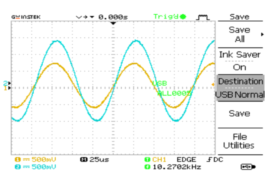


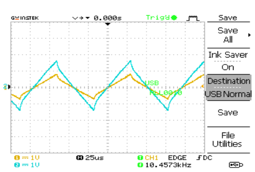
Fig. 8: Rectangular Waveform

4 Results and Discussion

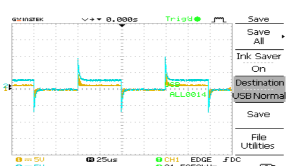
The different signal between input excitation signal and output produces according differential probes could be ration on 2:1 that means the input excitation signal is higher than output produce. It could be explain as base on the coil concept on differential probe. The primary coil turn on differential probe is more than secondary coil turn on differential probe. Fig. 9 Show the three type of input excitation signal where output produce according ratio of coil. Fig. 9 show the waveform at which the blue line waveform signal is representing the input from function generator and the yellow line is output signal from the differential probe. Fig. 9(a) is an ac waveform, (b) triangle waveform and (c) rectangular waveform



(a)



(b)

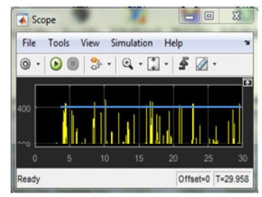


(c)

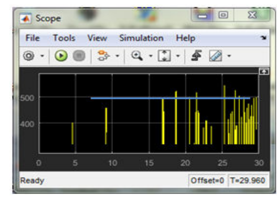
Fig. 9: Waveform signal from Differential Probe (a) AC signal, (b) Triangle Signal and (c) Rectangular Signal

4.1 AC current excitation signal

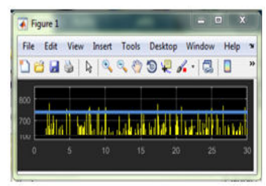
By following the result of output produced from differential probe after detect the crack defect on carbon steel plate by using AC signal is show in Fig. 10. The clear signals in defect identification are shown in frequency of 30 kHz at Fig. 10(b). From here the depth of defect will identified when the signal from the graph are surpassed the blue line marked on the graph. The significant differences of amplitude signal can be explain respectively by a) with 10%-20% amplitude signal for defect identification in 10kHz frequency, b) 50%-60% amplitude signal for defect identification in 30kHz frequency, c) 30%-45% amplitude signal for defect identification in 60kHz frequency and d) 20%-30% amplitude signal for defect identification in 90kHz frequency. When the higher frequency being set then travelling signal in depth of crack identification is low and if low frequency is set then low signal responses for defect detecting be produced.



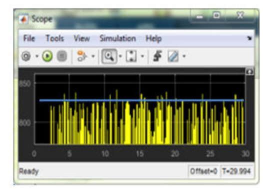
(a)



(b)



(c)

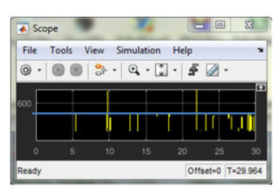


(d)

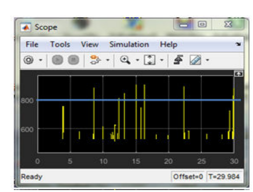
Fig. 10: AC excitation source apply at Differential Probe with frequency, a) 10kHz, b)30kHz, c)60kHz, d)90kHz

4.2. Pulse excitation signal

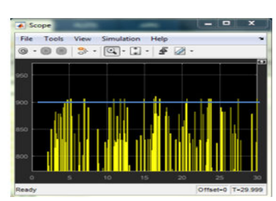
Through the pulse excitation signal, when the lower frequency is setting then the clear signal and high amplitude signal were produced when the differential probe measure the crack on the plate. It can be shown in Fig 11. According in Fig 11(a) and (b) the differences of amplitude signal was clearly by respectively a) with 70% - 90% of signal amplitude and b) 50% - 80% signal amplitude with each frequency setting are 10kHz and 30kHz. Apart from that the differences amplitude of signal are lower than 30% when the frequency are increased from 60 kHz and above.



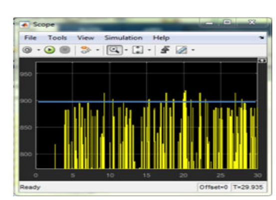
(a)



(b)



(c)

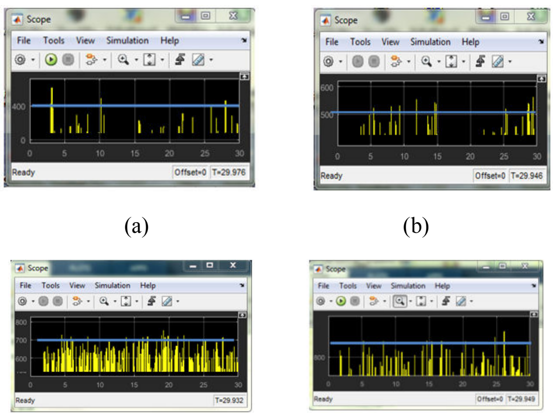


(d)

Fig. 11: Pulse excitation source apply at Differential Probe with frequency, a) 10kHz, b)30kHz, c)60kHz, d)90kHz

4.3 Triangle excitation signal

According the triangle waveform for excitation signal and the good selection frequency is 30 kHz by following the Fig 12. From here the high difference signal could be measure when detect the crack defect on plate with the difference amplitude of signal is in 20% until 70% with accordance of Fig 12(b). Nevertheless the high difference signal could be found in Fig 12(a) within 20% - 80% and frequency 10 kHz but the responses of crack detection is low comparing the Fig 12(b).



(a) (b)

(c) (d)

Fig. 12: Triangle excitation source apply at Differential Probe with frequency, a) 10kHz, b)30kHz, c)60kHz, d)90kHz

5 Conclusions

This paper presents an experimental study on the MES method to measure the depth of defect for carbon steel plate. The results were analyzed showed that the different types of excitation signal and frequency in defect measuring will be effect of the high amplitude of defect signal and the defect response. By looking on the ac excitation signal (ACES) when the frequency for signal excitation is low then response time low of output from the differential probe is low but when the frequency is high then amplitude of output from differential is low. The ideal frequency setting by using ac excitation signal for differential probe are in range 30 kHz until 60 kHz. For pulse excitation signal (PES) the good frequency setting for input excitation signal are 10 kHz until 30 kHz. It’s because the signal are produce from differential probe’s output are noticeable which in range of 50% - 90% amplitude of output signal. Lastly best of triangle excitation signal (TES) frequency setting is 10 kHz to 30 kHz respectively the high amplitude of output from differential probe are 20% to 80% range signal. The results show clear evidence that this method can be a potential tool to apply for the depth crack measurements according frequency and types of excitation signal, where the industrial structural materials are covered with non-conductive insulations coatings. The future research of the authors will in clued defect classification in multi-excitation signal with layer surface.

References

1. Abbas S, Khan TM, Javaid SB, Ahmed SA, Haider SS, Rajar Z. Low Cost Embedded Hardware based Multi- Frequency Eddy Current Testing System Depth of Penetration. 2016;1–6.
2. Voulgaraki C, Poulakis N, Theodoulidis T. Theoretical simulations and quantitative magnetic field measurements for eddy-current testing with an HTS SQUID system. IEEE Trans Appl Supercond. 2013;23(4).
3. Shejuan Xie , Zhenmao Chen , Hong-En Chen , XiaoweiWang , Toshiyuki Takagi and TU. Sizing of Wall Thinning Defects Using Pulsed Eddy Current Testing Signals Based on a Hybrid Inverse Analysis Method. 2013;49(5):1653–6.
4. Li Y, Chen Z. Pulsed Eddy Current Testing Based on Gradient Magnetic Field Measurement. 2012;1:3–6.
5. Tian GY, Morozov M, Takahashi S. Pulsed eddy current testing of thermally aged and cold-rolled fe-cu alloys. IEEE Trans Magn. 2013;49(1):517–23.
6. Stubendekova A, Smetana M, Janousek L. Non-destructive Testing of Artificial Knee Joint by Eddy Current Method precise control of the probe movement . The measurement. 2014;630–3.
7. Barbato L, Poulakis N, Tamburrino A, Theodoulidis T, Ventre S. Solution and Extension of a New Benchmark Problem for Eddy-Current Nondestructive Testing. IEEE Trans Magn [Internet]. 2015;51(7):1–7. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84936792056&partnerID=tZOtx3y1
8. François Caire1, Denis Prémel1 and GG. Fast computation of the fields diffracted by a multi-layered conductor with non-parallel rough interfaces. Application to eddy-current non-destructive testing simulation. IEEE Trans Magn. 2015;51(3).
9. S K Burke. Crack Depth Measurement using Eddy-Current. 2016;1–8. Available from: http://www.ndt.net/apcndt2001/papers/1032/1032.htm
10. Center NR. A Web Resource [Internet]. 2016. Available from: www.ndt- ed.org/Education Resources/ Community College/ Eddy Currents/ cc_ec_index.htm,2016
11. Enokizono M, Tsuchida Y, Chady T. Crack Size and Shape Determine by Moving Magnetic Field Type Sensor. 1998;34(4):1252–4.
12. Wang J, Yusa N, Fukutomi H, Hashizume H. Low Frequency Eddy Current Inspection of Wall-thinning of Large Pipes by Bobbin Coils. :4–7.
13. Heidari T, Seidfaraji H, Sadeghi SHH, Moini R. A fast analysis technique for electromagnetic interaction of high-frequency ac current-carrying

wires with arbitrary-shape cracks in ferrous metals. IEEE Trans Magn. 2013;49(3):1101–7.
14. Bowler NCH and JR. Eddy-Current Imaging of Buried Cracks by Inverting Field Data. 1992;28(March):1336–9.
15. Lambert M, Nouguier F, Zorgati R. Eddy-current modeling of a continous conductivity profile resulting from a diffusion process. IEEE Trans Magn. 2011;47(8):2093–9.
16. Koliskina V, Kolyshkin A. Mathematical model for eddy current testing of metal plates with two cylindrical flaws. 2015 IEEE 15th Int Conf Environ Electr Eng EEEIC 2015 - Conf Proc. 2015;(6):374–7.
17. Theodoulidis T, Skarlatos A. Eddy current interaction of an arbitrarily positioned probe coil with a conductive cylinder. IEEE Trans Magn. 2012;48(8):2392–4.
18. Båvall L. Determination of thickness of silver coatings on brass by measuring the impedance of a thin elliptic coil. IEEE Trans Instrum Meas. 2007;56(3):790–9.
19. Betta G, Ferrigno L, Laracca M, Burrascano P, Ricci M. Optimized complex signals for Eddy Current Testing. Conf Rec - IEEE Instrum Meas Technol Conf. 2014;1120–5.
20. Schroeder MR. Synthesis of Low-Peak-Factor Signals and Binary Sequences with Low Autocorrelation. IEEE Trans Inf Theory. 1970;16(1):85–9.
21. Lee KH, Baek MK, Park IH. Estimation of deep defect in ferromagnetic material by low frequency eddy current method. IEEE Trans Magn. 2012;48(11):3965–8.
22. Coil HTS, Sasayama T, Ishida T, Matsuo M, Enpuku K. Thickness Measurement of an Iron Plate Using Low-Frequency Eddy Current Testing. 2016;26(5):1–5.
23. Bernieri A, Betta G, Ferrigno L, Laracca M. Multi-frequency ECT method for defect depth estimation. 2012 IEEE Sensors Appl Symp SAS 2012 - Proc. 2012;114–9.
24. Xie S, Chen Z, Takagi T, Uchimoto T. Efficient numerical solver for simulation of pulsed eddy-current testing signals. IEEE Trans Magn. 2011;47(11):4582–91.
25. McKeehan LW. Electrical resistance of nickel and permalloy wires as affected by longitudinal magnetization and tension. Statew Agric L Use Baseline 2015. 2015;1(5):1930.