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DEFECT SIGNAL ANALYSIS FOR NONDESTRUCTIVE TESTING ASSESMENT

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ABSTRACT

For fast assessment of defects in conductive materials, Eddy current testing is a most widely non-destructive testing (NDT) evaluation methods utilized in industry, especially in oil and gas, aircraft, nuclear and coating industries. Experimental studies of eddy current testing have emerged as an important approach alongside numerical modelling. This paper focus on investigating the defect signal characteristics of carbon steel pipe weld coating inspection using different frequency eddy current testing. The optimum frequency of carbon steel pipe weld coating is verified. Tests have been conducted utilizing positive and negative scanning method with frequency between 10 kHz to 100 kHz. Artificial defect use of this test is the horizontal affected zone (HAZ), centre line and transverse crack. Experimental results showed the frequency can be impression to the amplitude and phase angle eddy current testing signal. The optimum frequency for carbon steel weld plate is 100 kHz.

Keywords: eddy current testing, non-destructive testing, carbon steel pipe welds coating, optimum frequency, phase angle.

INTRODUCTION

Eddy current testing methods are derived utilizing the principle electromagnetic. Eddy current is circular electric current induced within conductor by a changing magnetic field in the conductor. This phenomenon explains by Faraday in his electromagnetic revelation (Smith *et al.* 2003)(Kim *et al.* 2004). Then Hughes recorded changes in the metal coil magnetic properties when placed proximate to metal objects (Postolache & Alegria 2009). This method relies on the electromagnetic induction to detect discontinuities in conductive material. Discontinuities such as geometrical changes, variation in material properties relating to conductivity and permeability and the presence of defects, both surfaces breaking and subsurface can be detected utilizing eddy current testing (Betta *et al.* 2002). This discovery has been the commencement point for research in the utilization of eddy current principle for material defect inspection.

Eddy current testing is used in many applications for defect inspection and thin coating measurement. The basic use of the non-destructive eddy current method is to detect the defect and crack in conductive weld material connection. The selection of the appropriate probe and eddy current equipment parameters setting is paramount to obtaining precise and valid inspection results. The eddy current signal from the inspection is used to characterize the defect profile.

This method also useful in detecting corrosion damage and thinning. The technique is used to make corrosion and thinning measurements on aircrafts and heat exchangers (Through & Cheng 2012). Material permeability and conductivity is the most factors affecting the defect signal in eddy current non-destructive technique. Therefore, eddy currents can be used to detect material types and to determine if a material is exposed to high temperatures, since such treatment changes the conductivity of certain materials.

Defect signal is a signal when scanning of samples with defects. The signal will appear in the defect area while doing the inspection. Signal defect depends on the length and depth of the defect. In this paper, inspections have been made to detect cracks in the carbon steel pipe weld coating using different frequency eddy current testing. Eddy current flaws testing unit Phasec 3 developed by General Electric has been used for detection of cracks in carbon steel pipe weld coating. The characteristic of signal eddy current testing for HAZ, transverse and centre line crack is analyzed. This research outcome is expected to be beneficial for fast defect identification using eddy current testing in industrial engineering practice.

RELATED WORK

Principles of Eddy Current for Non-Destructive Testing

Eddy current non-destructive method is developed based on the principles of electromagnetic induction. A harmonic field at a specific frequency (typically Hz-MHz) is produced by a time-harmonic current through a source coil, which induces eddy currents in the object under examination (Kim *et al.* 2004). The presence of a defect or discontinuity behaves as a high resistance barrier which disturbs induced current flows. The resulting perturbations of the associated magnetic field are measured. This method can be described utilizing the Maxwell formula (Bossavit *et al.* 1996):

$$\nabla \times H = J + \frac{\partial E}{\partial t} \quad (1)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad (2)$$

$$\nabla . B = 0 \quad (3)$$

$$J = \sigma E \quad (4)$$

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Where
B: magnetic flux density (tesla)
E: electric field intensity (V/m)
D: electric flux density (C/m2)
H: magnetic field intensity (A/m)
σ: electric conductivity (mhos/m)
J: electric current density (A/ m2)

According to Ampere's law in (2), primary field H shown in Figure 1 is generated by a time varying current source in a coil (Through & Cheng 2012). This primary time varying magnetic field induces a secondary magnetic field that is proportional to changes the time-rate flux density:

$$\varepsilon = \frac{d\Phi B}{dT} \quad (5)$$

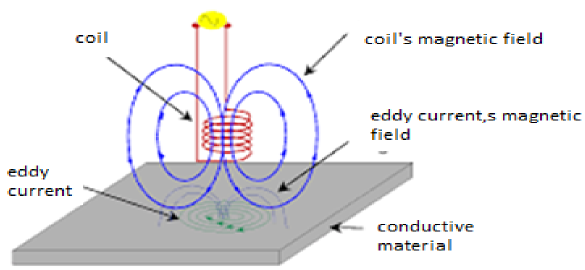

Figure-1. Principles of eddy current testing.

This secondary magnetic field interacts with the test material and results in currents induced inside the specimen. The induced currents are called eddy currents. Lenz's law describes these secondary magnetic field that opposes the source electromagnetic field due to the excitation coil, as shown in Figure-1. Thus the eddy current testing detection and defect characterization is primarily dependent on the secondary magnetic field which is generated inside the specimen. The idea is that the measured of secondary electromagnetic field in specimen material would change as the probe passes over the flaw, and the change can be used to detect and characterize the presence of a defect (He *et al.* 2011). The net change in the magnetic flux is linked to changes of the coil impendence (z), a complex parameter with magnitude |z| and phase angle ø as:

$$z = \frac{v}{i} = R + jX = |z|_{\phi} \quad (6)$$

Factors Affecting the Eddy Current Testing

Many factors, other than defects and cracks, will influence the eddy current inspection. The signal from an eddy current probe is a compilation of responses, including responses from flaws and defects, sample geometry, and probe lift- off (Amineh *et al.* 2003)(Lopes Ribeiro *et al.* 2012). Therefore, it might be hard to isolate a single effect. Successful evaluation of flaws or any other surface properties is possible when the other factors are known. The main factors affecting the coil response are listed in Table-1.

Table-1. Factor affects in eddy current testing.

Factor	Description
Material Magnetic Permeability	The strength of magnetic induction is influenced by the type of material. Permeability of ferrous metal is relatively several hundred. This will generate more induce secondary electromagnetic in ferrous metal than in non ferrous metal. Therefore, permeability has a very paramount influence on the eddy current defect signal.
Material electrical conductivity	One of the factors that affect the eddy current flow in surface material is conductivity properties of the material. Theoretically, with the same strength electromagnetic induced, materials having a higher conductivity will produce a greater flow of eddy current on the surface compared to material with low conductivity properties
Lift-off	Distance of the coil probe from the surface affects the ability to both induce and detect the eddy currents and thus very important. For example, this lift-off factor can be applied in order to measure the paint thickness effect.
Frequency	The depth penetration of electromagnetic waves in the material is influenced by the frequency of the waves. Electromagnetic waves with lower frequency will have a higher penetration.

Advantage of Eddy Current Testing

Eddy current inspection has several advantages:

- Sensitive to small cracks and other subsurface defects.
- Inspection gives immediate results.
- Environmentally friendly.
- Eddy current method no effect with wide of range temperature.
- Eddy current equipment can be made robust, portable and inexpensive.
- Can be used to inspect complex shapes and sizes of materials.

Reference Standards

Eddy current testing equipment must calibrate before defect inspection. The calibration process is essential for defect identification and defect sizing.

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Reference standards used to calibrate eddy current equipment and eddy current probe must comprise of the same material with the test piece to be quantified. The signal generated during defect inspection will be compared with the artificial defect signal that have known the characteristic of the defect specifications. This comparison signal allowed an inspector to identify the size and type of defect in test piece material (Blitz *et al.* 1981)(Neto & Faria 2014)(Betta *et al.* 2002).

For thickness measurement utilizing eddy current technique, the calibration for eddy current equipment and probe needs using various thickness of standard references. Various signals generate from the reference block will make the interpretation of test sample thickness expeditiously and accurately.

The calibration operation requires the use of a calibration standard, which is made of the same material as the test specimen. Various defects with dimensions are introduced into the calibration standard and the calibration standard is inspected prior to the test specimen. The calibration operation generally consists of rotating and scaling of one or more reference defects on the calibration standard (Blitz *et al.* 1981). The parameters obtained by the rotation and scaling of the reference signals on the calibration standard are then applied to the data collected from inspection of the test specimen (Betta *et al.* 2002). Figure-2. Depicts the rotation of a signal**.**

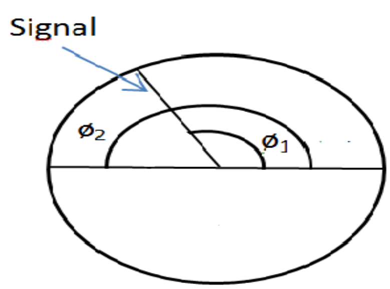


Figure-2. Signal rotation in eddy current defect detector equipment calibration

The rotation and scaling parameters are computed as follows. If $ø_1$ is the phase angle of the signal and it has to be rotated to a phase angle $ø_2$, then the rotation angle θ is given by (Blitz *et al.* 1981):

$$\theta = ø_2 - ø_1 \quad (7)$$

The scale factor is determined as:

$$S = \frac{r_1}{r_2} \quad (8)$$

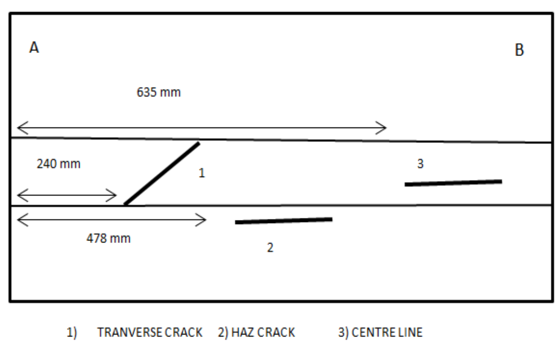
Where
S is thes scale factor
r_1 is the desired peak to peak scaling of the signal
r_2 is the original peak to peak value of the signal Eddy

MATERIAL AND METHOD

Material

The material use in this experiment is DF3 carbon steel pipe weld coating. The content of carbon may range from more than 0.015% to 3%. The mixtures of small amount of carbon change the mechanical properties of steel. The composite metal and carbon steel produce carbon steel with high mechanical strength, hardness and other valuable mechanical properties such as the conductivity and the permeability of the material. The work piece was carbon steel pipe weld coating containing a weld and artificial defect. The cracks in the weld pool are horizontal affected zone (HAZ), centre line and transverse crack which are varying in depths. Figure-3 shows the carbon steel pipe weld coating and defect schematic.

(a)



(b)

Figure-3. a) Carbon steel pipe welds coating b) Artficial defect schematic.

Method

Based on the flow chart in Figure-4, the inspection start by setting parameter eddy current instrument. The frequency and bridge probe setting is set to 100 kHz and 0.5 second. Phase and filter ratio eddy current testing for this inspection is set to 90 degrees and 50/300.For calibration setting, the probe must cross on slot 1.0 mm in the calibration reference block. Move the weld probe to the right and to the left through the slot 1.0 mm. Set the phase angle 90 ° and the signal deflection to the 80% - 100% FSH (full screen height).

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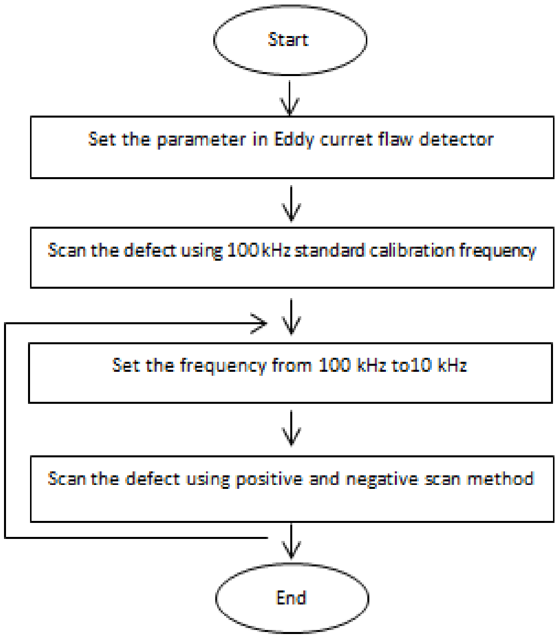

Figure-4. Steps involved in defect inspection.

Eddy current set Phase 3 can inspect the defect utilizing positive scan and negative scan. The distinguishment between the positive and negative scan method is a way of positioning the probe when making defect inspection. Figure-5 shows how to utilize positive scan and negative scan technique in defect inspection.

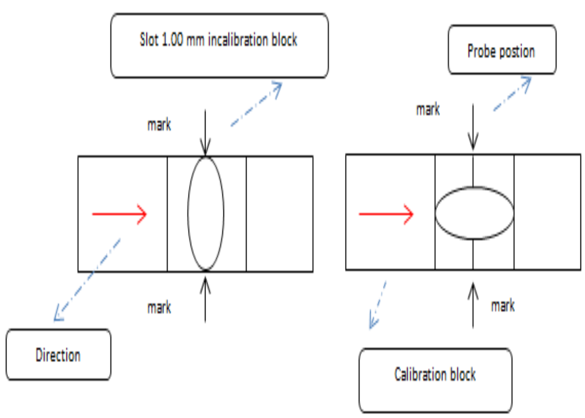

Figure-5. Positive and negative scan technique.

For complete coverage and comprehensive defect inspection using eddy current in metal weld area, the probe must be scanned over the weld area with managed movement. Probe-to-surface orientation must be maintained as probe wobble can affect defect signal interpretation. The experimental setup is shown in Figure-6. Inspections were carried out on defect types of HAZ, transverse and centre line.

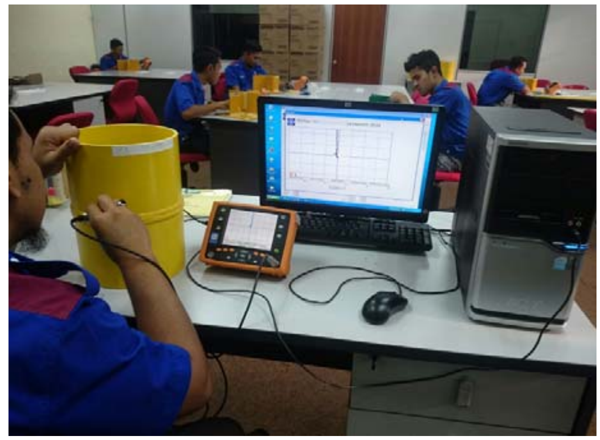

Figure-6. Experimental setup for carbon steel pipe weld coating defect inspection using eddy current testing.

RESULTS AND DISCUSSION

In the following, some of the obtained results are presented. Defect measurement of HAZ, centre line and transverse crack were performed using positive and negative scanning. The material used is carbon steel pipe weld coating. Gain for eddy current setting is 46 dB. Signal amplitude and phase angle are recorded in different eddy current frequency. Table-2 shows the signal phase angle for positive scan. The degree of the phase on three types of defects is decreased when decreasing the frequency.

Table-2. Signal phase angle for positive scan.

	Phase Angle (^{O})		
Frequency(kHz)	HAZ	Centre Line	Transverse
100	0	90	90
90	4	92	92
80	96	94	96
70	00	100	99
60	05	106	106
50	16	120	117
40	20	124	122
30	25	135	130
20	40	150	143
10	60	166	162

Signal amplitude is very consequential for the process of quantifying the depth of cracks in eddy current testing. The signal amplitude will compare with the signal amplitude during the calibration process for getting authentic value of crack depth on the work piece to be quantified. Signal amplitude values for the type of HAZ, transverse and centre line shows the inversely proportional to the frequency eddy current used during the scanning. This denotes a low frequency below 100 kHz is not suitable for making quantifications of carbon steel pipe weld coating. Signal amplitude for positive scan eddy current technique is shown in Table-3.

Table-3. Signal amplitude for positive scan.

	Amplitude (mm)		
Frequency(kHz)	HAZ	Centre Line	Transverse
100	7	34	31
90	9	28	24
80	5	18	17
70	2	14	15
60	0	11	9
50		7	6
40		4	5
30		3	4
20		2	2
10		1	1

In eddy current testing factors that affect signal quality as lift off and conductivity materials to be tested should be considered. This is to ascertain that the results obtained are precise. Signal for scan test utilizing positive methods shown in Figure-7. The experiment is carried out by utilizing a frequency between 10 kHz to 100 kHz.

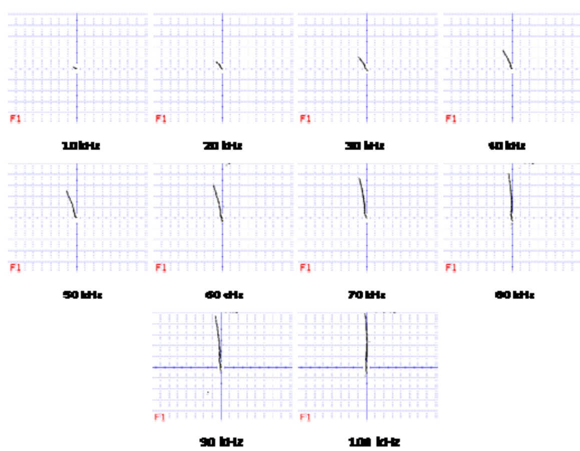

Figure-7. Positive scan signal.

In order to retrieve valid comparison of each type scanning method, experimental tests have been executed on carbon steel pipe weld coating with a similar parameter setting in both method scan. Phase angle measurement for negative scan eddy current technique is shown in Table-4.

Table-4. Signal phase angle for negative scan.

	Phase Angle (°)		
Frequency(kHz)	HAZ	Centre Line	Tranverse
100	270	270	270
90	273	274	275
80	275	276	276
70	281	280	281
60	288	286	285
50	295	296	296
40	305	307	305
30	315	314	312
20	320	319	318
10	345	342	343

Phase angle signal for negative scan method is inversely proportional to the frequency utilized. The optimum phase angle for negative testing is 270 degrees at 100 % FSH. This demonstrates the utilization of the appropriate frequency is important in quantifying the defect utilizing eddy current testing. The signal amplitude of the negative scan method decreases proportionally with decrease the frequency eddy current test utilized for HAZ, transverse and centre line defect. Optimum signal is the signal amplitude most proximate to the signal amplitude obtained during the calibration process. Optimum amplitude in negative scan for HAZ defect is 25 mm. Signal amplitude for negative scan eddy current technique is shown in Table-5.

Table-5. Signal amplitude for negative scan.

	Amplitude (mm)		
Frequency(kHz)	HAZ	Centre Line	Transverse
100	23	33	31
90	21	27	25
80	20	18	16
70	13	14	14
60	12	12	9
50	10	7	5
40	8	6	4
30	5	5	3
20	2	3	2
10	1	1	1

The optimum signal for a negative scan method should be in the 270 degree phase angle. For HAZ defect scanning the result show frequency at 100 kHz has signalled at 270 degree and signal amplitude most proximate to calibration signal. This shows the frequency of 100 kHz is the most optimal for negative scan eddy current method in carbon steel pipe weld inspection. Signal for scan test utilizing negative methods shown in Figure-8.

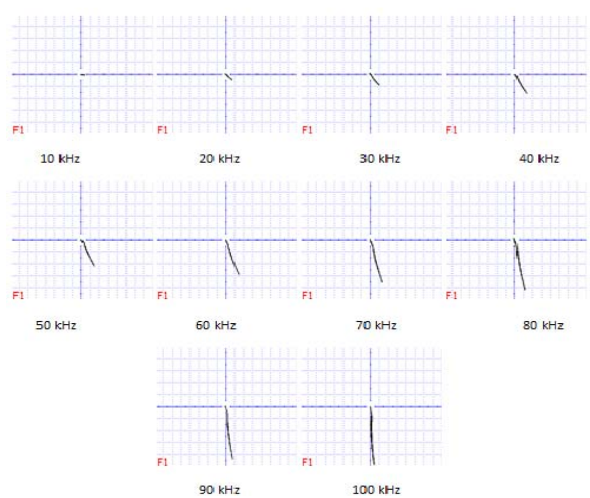

Figure-8. Positive scan defect signal for centre line crack.

Selection the optimum gain in eddy current instrument setting is paramount in crack inspection utilizing eddy current method. The optimum value of the gain can provide a defect signal with clear characteristic which is consequential in defect sizing. Figure-9 shows the defect signal for centre line cracks utilizing frequency 100 kHz to10 kHz and a gain of 40 dB, 42 dB and 44 dB. For positive scan method, the difference in phase angle signal defect for centre line commences at a frequency of 50 kHz. Signal phase angle incremented by increase the gain from 40 dB to 44 dB.

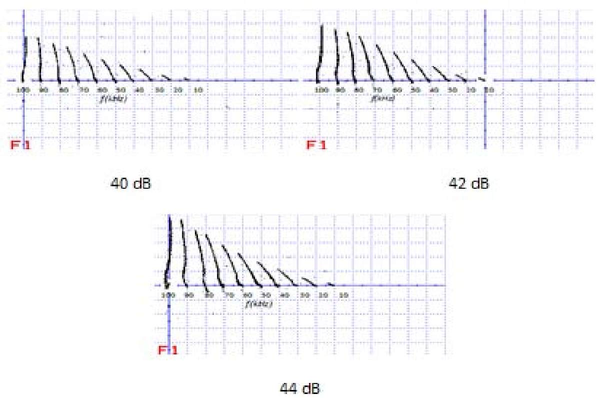

Figure-9. Negative scan defect signal for centre line crack

Characteristics of the defect signal for negative scan method shows homogeneous attributes with the positive scan method. Phase angle defect signal difference commences at 50 kHz. This shows that the selection of the appropriate gain is consequential for the defect signal analysis in defect inspection using eddy current testing. Base on result in positive and negative scanning, similar results were obtained on the other type of crack, confirming the capability of the both scan techniques to quantify the measurement value of the defect depth. Some considerations can be made:

- The different frequency in eddy current testing affect the signal amplitude and phase angle of the output signal.
- For carbon steel pipe weld coating 100 kHz is the most suitable frequency for defect measurement.
- Phase angle and amplitude signal of eddy current for HAZ, centre line and transverse crack measurement are inverse proportional to the frequency use in the inspection

CONCLUSIONS

In this paper a characteristic of the eddy current signal for HAZ, transverse and center line crack is investigated. The suitable frequency for optimum eddy current defect inspection is distinguished. Tests carried out in experimental environment have shown the suitability of positive and negative scan method in various types of defect measurement.

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