Detection of Thickness Variation in Steel using Pulse Eddy Current Technique in Time Domain

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Abstract

In contrast to single frequency conventional eddy current technique (ECT), in pulse ECT the coil is excited by repetitive broadband pulse. The pulsed excitation contains wide spectrum of frequencies. Each frequency has different penetrability and hence using pulsed eddy current (PEC) technique, large areas of structure with multiple variations in thickness can be scanned without the need for parameter or setup changes.

This paper describes a pulsed eddy current based non-destructive testing system used for detection of thickness variation in the stainless steel sample. For this purpose, a PEC probe having ferrite core driving coil with giant magneto-resistive (GMR) sensor as pick up sensor has been developed. The PEC instrumentation consisting of coil driving circuit, instrumentation amplifier circuit, data acquisition module and signal processing software has been developed.

The PEC response signals obtained from 1 mm to 6 mm thick stainless steel sample were investigated. Two time domain features, namely peak value and time to peak, of PEC response are used for extracting information about thickness variation in stainless steel plate. The variation of peak value and time to peak with thickness was compared. A customized signal processing software was developed to display the thickness variation of the tested sample. The technique can be used to detect the wall thinning in the pipelines of plants without removing the thermal insulation, where conventional NDT methods such as ultrasonic testing (UT) are difficult to apply.

1. Introduction

In power plants steel pipelines are used. In order to increase the thermal efficiency, the steel pipelines are covered with a thermal insulator made from the materials having low thermal conductivity to refrain from thermal emission and absorption. The local wall thinning is a point of concern in the pipe lines. Hence to ensure that wall thinning is within acceptable limits, a continuous periodic monitoring of the pipelines is needed. The conventional eddy current technique (ECT) and ultrasonic testing (UT) are difficult to apply in the inspection of wall thinning in the pipelines of power plants [1]. Therefore, a new pulse eddy current based non destructive technique has been developed. In contrast to single frequency conventional ECT, the pulse ECT coil is excited by repetitive broadband pulse. The pulsed excitation contains wide spectrum of frequencies. Each frequency has different penetrability and hence the PEC technique has potential for providing deeper information about the test sample. Using PEC technique, large areas of structure with multiple variations in thickness can be scanned without the need for probe or setup changes. In addition to this, the offline analysis can be done for lift off compensation. The conventional ECT is usually employed for thickness measurement of thin materials whereas PEC technique can be used
for both thin and thick materials. Inductive pick up coils used in conventional ECT are less sensitive to low frequency fields needed for penetration in thick material. However there is no such issue with magnetic field sensors (like GMR sensor or Hall sensor) which are usually used in PEC technique [2].

This paper describes a PEC system developed for detecting thickness variation in steel. For this purpose, a PEC probe having ferrite cored driving coil with giant magneto-resistive (GMR) sensor as pick up sensor and instrumentation consisting of a coil driving circuit, a sensitive instrumentation amplifier, an A/D converter and a computer with data acquisition & signal processing software were developed. The PEC response signals obtained from 1 mm to 6 mm thickness change in steel plate were investigated. Two time domain features, namely peak value and time to peak, of PEC response were used for extracting information about thickness variation in steel. A program was developed to display the thickness variation of the tested sample.

2. Pulse Eddy Current Theory

Pulse eddy current (PEC) is a new emerging technology in the eddy current non-destructive testing (NDT) and has gained considerable research attention in recent years. Instead of using single frequency continuous alternating current as in conventional ECT, in pulse eddy current (PEC) testing, the exciting coil of PEC probe having inductance \(L\) and resistance \(R\) is excited by pulse train \([m(t)]\). Using Fourier Series theorem, the frequency domain representation of \([m(t)]\) is given by Eq. 1.

\[
(1) \quad m(t) = \frac{d}{T} + \sum_{n=1}^{N} (A_n \sin(\omega_n t) + B_n \cos(\omega_n t)) \quad n = 1,2,3, \ldots.
\]

Here, \(T\) is pulse period, \(d\) is pulse time in one period, \(n\) is the harmonic order, \(t\) is the transient time, \(N\) is the total number of harmonic order, and \(\omega_n \equiv 2\pi n/T\) is the harmonic angular frequency. \(A_n\) and \(B_n\) are the coefficients.

\[
(2a) \quad A_n = (1 - \cos(\omega_n d))/n\pi
\]

\[
(2b) \quad B_n = \sin(\omega_n d)/n\pi
\]

The current \(i(t)\) drawn by the excitation coil, when it is in air, can be given by the equation:

\[
(3a) \quad i(t) = I_p(1 - e^{-t/\tau}) \quad \text{[for increasing exponential current]}
\]

\[
(3b) \quad i(t) = I_i( e^{-t/\tau}) \quad \text{[for decreasing exponential current]}
\]

Here, time constant \(\tau = L/R\) and final current \((I_p)\) and initial current \((I_i)\) are equal to \(V_s/R\) where \(V_s\) is the pulse amplitude. The circuit model for excitation coil current is shown in Fig. 1. The resulting current through the exciting coil generates transient eddy currents at the surface of the conductive test sample that propagate down into the material. The induced eddy current generates an electromagnetic field which is in opposition to the primary magnetic field generated by the exciting coil. The pick-up sensor is used to sense the net magnetic field.

The PEC response signal \(R(t)\) [3] is composed of the sinusoidal waves of the frequencies appeared in the input pulse and expression for it can be obtained as follows. In Eq. 1, considering the single frequency sinusoidal exciting signal, if we assume that the exciting signal is \(\sin(\omega_n t)\) then the corresponding pickup signal is:
and if we assume that the exciting signal is $\cos(\omega_n t)$ then the corresponding pickup signal is:

$$4b \quad R_n \cos(\omega_n t) = Im_n \sin(\omega_n t)$$

Here $R_n$ and $I_n$ are the real part and the imaginary part of the pickup signal.

The PEC response signal $R(t)$ is obtained by substituting the corresponding pickup signal of $\sin(\omega_n t)$ and $\cos(\omega_n t)$ in eq (1).

$$5 \quad R(t) = \sum_{n=1}^{N} ((A_n \Re_n - B_n \Im_n)\sin(\omega_n t)) + \sum_{n=1}^{N} ((A_n \Im_n + B_n \Re_n)\cos(\omega_n t))$$

**3. Experimental PEC System**

Fig. 2 shows the PEC experimental set-up developed for detection of thickness variation in stainless steel plate. The function generator is used to produce a rectangular waveform of duty cycle 30% and repetition frequency 2 KHz. The waveform is fed to a coil driver circuit, which excites the coil in the PEC probe with pulsed current. The PEC probe consists of a cup-shaped ferrite core, driving coil and giant magneto-resistive (GMR) sensor. The driving coil is a copper wire having 50 turns wound on the cylindrical central pod of the ferrite core. The GMR sensor is positioned in the central pod of the PEC probe to measure the $Z$-component of the resultant magnetic field ($B_z$). The PEC response measured by the GMR sensor is amplified by the instrumentation amplifier and is acquired using a sampling rate of 1MHz. The PEC response is smoothened and observed on the computer screen. The program has the provision to store the sampled data in the computer, so that user can reproduce the graph when needed for carrying out offline analysis. In the tests, the PEC probe is in contact with the sample surface to eliminate lift-off effects. The system developed has been used to detect the thickness variation in the stainless steel plate shown in Fig. 3. The plate contains thickness varying from 1 mm to 10 mm with an increment of 1mm.
4. Results and Discussion

The PEC response signals obtained from 1 mm to 6 mm thickness change in stainless steel is shown in Fig. 4. The PEC response signals have a fast rise to a peak followed by a slower decay. As the thickness of the sample increases, the cross-sectional area for induced eddy currents increases, leading to higher secondary magnetic field, this results in decrease in the detected magnetic field and hence pulse amplitude. After peak amplitude is attained, the PEC response signals show a slower decay. The eddy current decays in the test sample to zero due to the electrical resistance of the material under test [1].

The PEC response shows that the thickness variation in the stainless steel plate affects both the peak height and time to peak. Thus, these two time domain features are extracted from the PEC response and used to determine thickness variation in the stainless steel plate. Fig. 5 shows the variation of peak value with sample thickness. As the thickness increases, the peak amplitude decreases. Fig. 6 shows the variation of time to peak with sample thickness. The time to peak increases as the thickness increases.
A simple way to predict the thickness of conductive stainless steel sample by using a pulsed eddy current method has been proposed. The proposed method can be used to detect the thickness variation in stainless steel. Two time domain features, namely peak value and time to peak, of PEC response are used for extracting information about thickness variation in stainless steel plate. The peak value decreases as the sample thickness increases whereas the time to peak increases with increase in thickness. The method can be used for the detection of the wall thinning in the steel plate.

Fig. 4: Pulse response at the different thickness of the steel plate

Fig. 5: Peak value versus sample thickness

Fig. 6: Time to peak versus sample thickness

5. Conclusion

A simple way to predict the thickness of conductive stainless steel sample by using a pulsed eddy current method has been proposed. The proposed method can be used to detect the thickness variation in stainless steel. Two time domain features, namely peak value and time to peak, of PEC response are used for extracting information about thickness variation in stainless steel plate. The peak value decreases as the sample thickness increases whereas the time to peak increases with increase in thickness. The method can be used for the detection of the wall thinning in the steel plate.
pipelines of power plants without removing the thermal insulation, where conventional NDT methods such as ultrasonic testing (UT), eddy current testing (ECT) are difficult to apply.

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7. References