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The Effects of Lift-Off from Wall Thinning Signal in Pulsed Eddy Current Testing

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In order to know the effect of surface irregularity in the detection of local wall thinning of pipeline using pulsed eddy current (PEC), the lift-off effects on PEC signal have been investigated. Three kinds of parameters in the PEC signal, which is "peak amplitude", "time to peak amplitude" and "time to zero crossing" are analyzed to separate the lift-off effects in the PEC signal. The distance from sensor to the bottom of sample which is the total thickness of combined insulator and sample is kept constant. The magnitude of the differential peak amplitude is increased with increasing sample thickness, the time to peak amplitude is increased with increasing the sample thickness. To determine the effect of lift-off, a number of balanced transient responses combining wall thinning locations and lift-off distances were plotted.

Keywords : NDT, pulsed eddy current, lift-off effect, wall thinning, pipeline

1. Introduction

The local wall thinning is a point of concern in most of the steel structures, such as the pipe lines in the power plant and oil industries [1]. In order to increase the thermal efficiency, the pipelines of nuclear power plants (NPPs) are covered with thermal insulator to refrain from thermal emission and absorption. Therefore new Non-Destructive test (NDT) methods for detecting the wall thinning without removing the insulator are necessary. The conventional NDT methods such as Ultrasonic Testing (UT), Eddy Current Testing (ECT) [2], are difficult to apply in the inspection of wall thinning in pipelines of power and oil industries since these techniques requires the direct contact between the sample and probe. The Pulsed Eddy Current (PEC) techniques have the potential to penetrate deeper into materials and return a wealth of information due to their frequency content. However, PEC is also not free from the demerits of ECT such as lift-off and skin depth effect [2]. Principally PEC has been developed for surface, subsurface flaws measurements and corrosion detection in the multilayered structures [3]. The insulator surface encircling the pipeline is irregular; therefore the distance between probe and pipe (lift-off) is not constant. When we apply PEC technique in the pipeline covered with insulator, the total PEC signal is represented as the summation of the signal from thickness variation of insulator and wall thinning by corrosion. Therefore it is important to separate each term from total PEC signal to evaluate the wall thinning of pipeline nondestructively. The lift-off point of intercept (LOI) feature was successfully used to map out the corrosion [4], to detect the cracks under installed fasteners [5], and to quantify the defects and their locations in a multilayered specimen [6]. In this study another method which separates the lift-off and wall thinning parts from total signal was introduced. The tested sample is made of a stainless steel having thickness varying from 1 mm to 5 mm and is laminated by a plastic to simulate the thermal insulation of pipelines in NPPs. From this piece of work, it is possible to see the separation between the signals with thermal insulation and wall thinning at the point identified as time to peak value.

2. Experimental Setup

The configuration of PEC system has been shown in Fig. 1, the system mainly consists of a driving pulse amplifier to excite the coil, probe, a PEC amplifier, A/D converter and a computer with data acquisition. The probe consists of an excitation copper coil of 200 turns wound on a cylindrical ferrite core having 15 mm inner and 23 mm outer diameters to induce the eddy currents in to the test specimen, to detect

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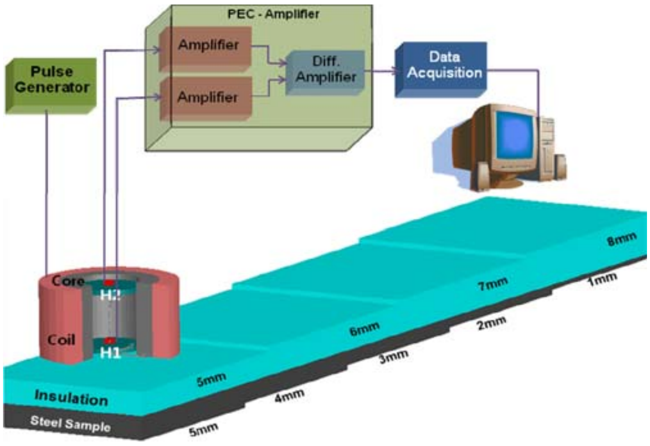

Fig. 1. (Color online) Experimental setup detecting the lift-off effect of PEC system; differential probe, sample and insulator.

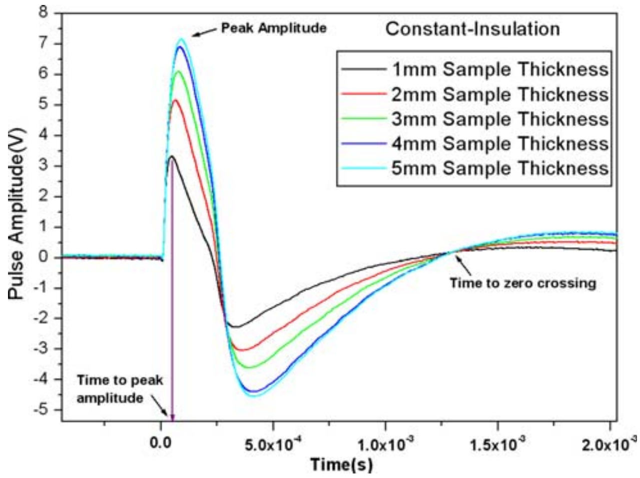

Fig. 2. (Color online) Composite graph showing the effect of sample thickness on balanced transient responses for PEC probe.

the PEC response two Hall-sensors (H_1 and H_2) are placed at the inner side top and bottom axial center of the probe as shown in Fig. 1. If the probe is on the insulated sample surface, the response from hall-sensor H_1 raises slower than H_2 to reach its maximum value because the Hall-sensor H_1 is nearer to the sample surface, so that the effect of induced eddy currents are more on H_1 than H_2 [7]. The magnetic fields detected by the two sensors are subtracted using the differential amplifier and the resultant signal is used as the probe signal. The exploitation of hall-sensor as a detecting sensor gives the frequency independent sensitivity from DC to several hundred kHz [8]. The calibration sample is a stainless steel of thickness varying from 1 mm to 5 mm and a plastic plate having different thickness is attached on the flat side of the sample to simulate the lift-off of thermal insulation as shown in the Fig. 1. Usually the field produced by the excitation coil is larger than that of induced eddy currents field, hence this excitation field dominate the perturbed eddy current fields which are generated due to the geometric changes in the sample such as metal loss, cracks, etc.. Therefore it is difficult to detect the flaws, geometric changes in the specimen. To overcome the excitation field's interference problem, the difference probe has been used.

3. Experimental Results and Discussion

The most frequently used parameters in PEC signal analysis are "peak amplitude", "time to peak amplitude" and "time to zero crossing", as depicted in Fig. 2. From this figure, the magnitude of the differential peak amplitude is increased with increasing sample thickness. It is attributed to the increase of conductivity volume associated with the increase of sample thickness. The larger conductivity area leads to higher induced eddy current [9]. Technically we can understand the differential pulse response is proportional to the induced eddy currents in the sample, because the excitation field is nullified by the differential arrangement of two Hall-sensors ($V_{diff} = H_2–H_1$), only the effect of induced eddy current fields are detected by the probe. In conclusion, the large cross sectional conduction area leads to higher induced eddy currents [9] so that the peak value of the detected pulse is increased with increasing sample thickness as shown in Fig. 2.

To determine the effect of lift-off, a number of balanced transient responses combining sample thickness and lift-off distance were plotted in Fig. 3, which shows that the normalized peak amplitude does not change at constant sample position with different insulation thickness. From this plot we can state that the value of peak amplitude does not depend on the insulation thickness. According to the skin-depth relationship it can be said that a rectangular

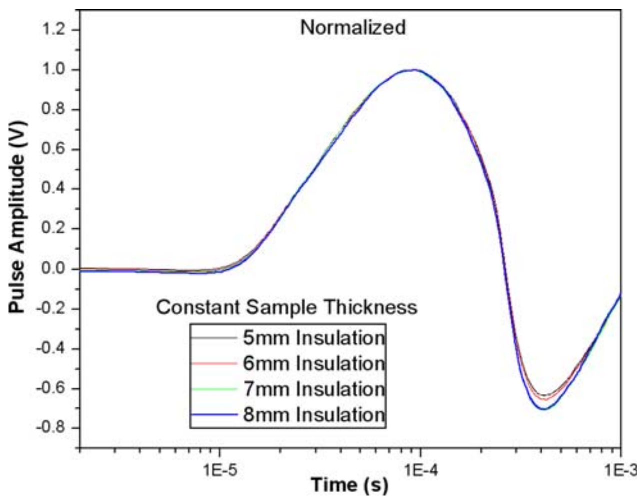

Fig. 3. (Color online) Change of normalized peak amplitude at constant sample position with different insulation thickness.

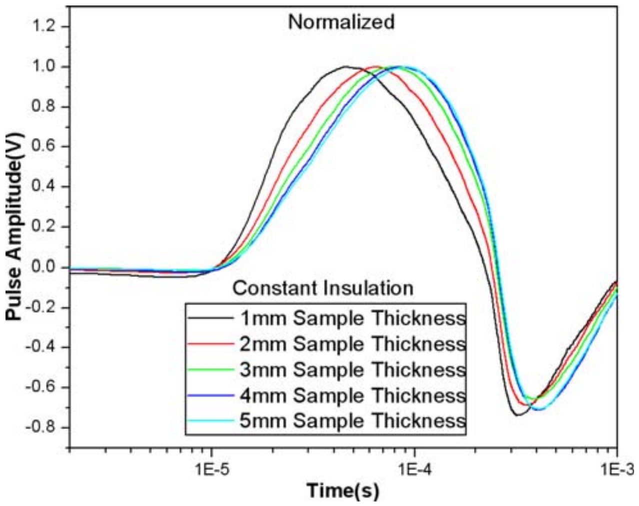

Fig. 4. (Color online) Change of normalized peak amplitude at 7 mm insulation thickness with different sample thickness.

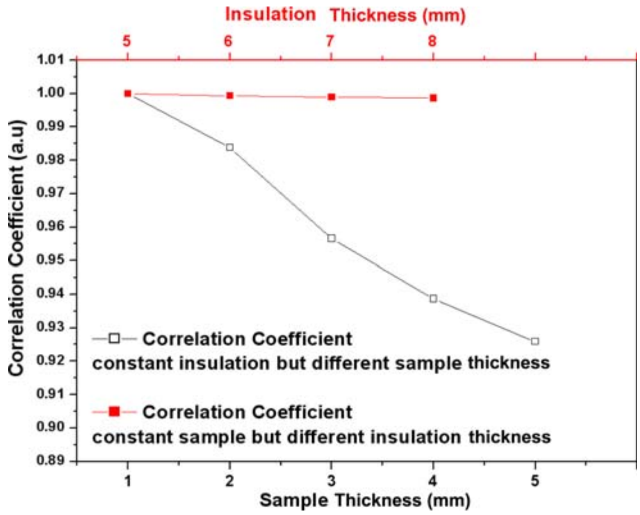

Fig. 6. (Color online) Correlation coefficient of the signal with constant insulation but different sample thickness, and constant sample but different insulation thickness.

pulse penetrates multiple depths simultaneously which allows us to determine a number of parameters such as defect size and location associated with the permeability and conductivity of the sample [10]. The change of lift-off does not affect any of these parameters, therefore no change of time to peak amplitude attributed to the fact that insulation thickness is nothing to do with skin-depth relation.

Fig. 4 shows the results which are measured with different sample thickness under the constant insulation thickness; it can be observed that the time to peak amplitude is increased with increasing the thickness of test sample. In the analysis of time to peak amplitude, the arrival time of the peak is always related to the filtering property of test sample to filter magnetic fields and hence contains the information of sample thickness.

Fig. 5 is an expanded view of Fig. 3 and Fig. 4, and it clearly shows the separation between curves with lift-off

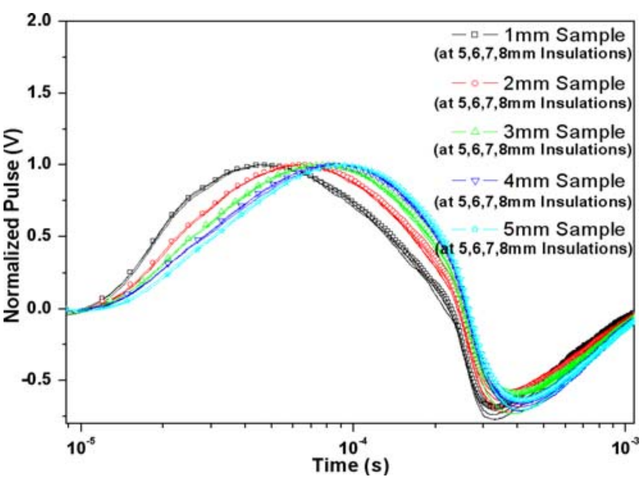

Fig. 5. (Color online) Pulse amplitude as a function of sample thickness at insulations of different thickness.

and those with both lift-off and thickness change. With the variation of the lift-off distance, the shape of the time domain balanced transient response changes tremendously. However, one particular feature does not vary significantly. The last feature used by researchers is the time to zero crossing. Normally, this feature provides information of the location of the defect and the condition of the test object [4]. Specifically, air gap, or simple plate separation, has the earliest time to zero crossing. This is explained by the fact that total thickness of metal below the sensor remains constant. Therefore, the time to zero crossing does not change with the lift-off variation.

As shown in Fig. 5 time to zero crossing does not change with lift-off variation, but it change with wall thinning. The shift of time to zero crossing pointed with decreasing time corresponds to the metal loss accompanied by wall thinning. In addition, to obtain a reliable parameter for the effect of lift-off variations for the PEC signal the correlation coefficient between the signal from insulator thickness variation and sample thickness variation has been devised. The correlation coefficient reflects a class of statistical relationship between the observed data values. Firstly, we obtained the relationship between the normalized peak amplitudes on the condition that same sample thickness but different insulation thickness) and it is observed that the correlation coefficient is approximately unity since all the signals under this condition is almost similar there is no change in magnitude. Secondly, the same method of correlation coefficient calculation was applied on the condition that sample thickness varies but lift of is kept constant. In this case the correlation coefficient is gradually decreasing with respected to the change in sample thickness *n* as shown in Fig. 6. the correlation function used in this method evaluates the sequential relation between two signals i.e. the similarity of the two waveforms as a function of time lag applied to one of them. The correlation coefficient will be unity if there is no lag in the second signal with first signal conforming that both the signals are similar. In other words the correlation coefficient is close to unity if the two signals are similar and deviates from unity depending on the extent of dissimilarity between the two signals. From Fig. 6 it is clear that the correlation coefficient of the signal with constant sample thickness but different insulation thickness is unity, but that of constant insulation but different sample thickness tends to decrease linearly with sample thickness.

4. Conclusion

By analyzing the behavior of pulse amplitude, it is possible to identify positively the effect of insulator irregularity but also get a quantitative assessment of wall thinning by corrosion. The observed PEC signal include the effects of these two terms, one is come from the variation of sample thickness and the other is insulation thickness. It is difficult to separate the portion of these two terms from the observed PEC signal because PEC signal depends on not only sample thickness but also insulator thickness. We have separated these two terms using LOI (lift-off intersection). The time shift of PEC signal was not observed by the variation of insulation thickness, but it was taken place by the variation of sample thickness. The time to peak amplitude increased with sample thickness but it did not depend on the insulator thickness. This can be used to separate the surface irregularity effect in the NDT using PEC related with wall thinning of pipeline and corrosion under insulation.

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