Corrosion Steel Inspection under Steel Plate Using Pulsed Eddy Current Testing

*Raynar Co., Ltd./Kunjang University College, Daejon, South Korea
**SAE-AN, Seoul, South Korea
(raynar@raynar.co.kr)

Abstract. Pulsed eddy current inspection techniques were derived from the conventional eddy current testing technology, based on the fundamental principle of an eddy current coil, but using periodic ultrasound pulses. The authors first introduce the principle of pulsed eddy current inspection and some experimental measurement results using pulsed eddy current equipment. This technology can be applied to the field of impedance measurement.

Introduction

In this study, we used the pulsed eddy current (PEC) technique to improve the capability of depth difference measurement and studied a multi-pointing method to evaluate the thickness based on the variation in resistivity.

PEC technology was first developed by Libby [1] in 1971. The signal can be detected using Hall sensors or an induction coil.

Gibbs and Campbell (1991) were able to detect 7-mm-deep defects in the non-ferrous sections of aircraft structures using a Hall sensor as part of a bolt connection and by applying a PEC technique to 14-mm steel joints.

In the United States, GE developed a commercial PEC sensor for a 2D array that can be used to inspect aircraft parts [2]. As part of its Dutch RTD, the Shell Company developed equipment that can measure the corrosion under insulation.

In 2005, Suh et al. [3] studied the relationship between the driving coil inductance of a pick-up coil and the thickness of an aluminum specimen by measuring the change in the voltage detected with an induction coil, and found a linear correlation with the thickness.

Therefore, in this study, we measured the thickness of a carbon steel plate and aluminum plate by using the impedance method of PEC inspection. Using the results of the PEC impedance techniques, we were able to detect the corrosion of carbon steel, steel, and aluminum, as discussed below.

Principles of pulsed eddy current inspection

Unlike the existing eddy current inspection method that uses alternating current, the PEC technology applies a repetitive pulse voltage to a coil, generating a PEC at the coil or a Hall sensor to collect signals. To explain the eddy current testing principle, Figures 1 and 2 show that a magnetic field is formed around a coil when an alternating current is applied to it. This magnetic field produces eddy currents at the surface and subsurface of a specimen, which form a secondary magnetic field.
Eddy current testing is accomplished by checking the impedance of the eddy current for variations, which can be produced by defects such as cracks.

\[
\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \quad (1)
\]

where \( \delta \) = standard depth of penetration (mm)
\( \pi = 3.14 \)
\( f \) = frequency (Hz)
\( \mu \) = permeability (H / mm)
\( \sigma \) = electric conductivity (% IACS)

Eddy current testing uses a constant-frequency alternating current, as shown in Figure 2. Therefore, the skin effect formula in equation (1) shows that the penetration depth is inversely proportional to the square root of the frequency. In other words, the occurrence of a high-frequency eddy current only on the surface makes it favorable for surface inspection.

On the other hand, PEC inspection techniques, as shown in Figure 3, use a PEC coil with a rectangular pulse at a pulse repetition frequency. As shown in Figure 3, a square wave with a 50% pulse width is applied to the coil for broadband eddy current inspection. These broadband frequency eddy current pulses penetrate deeper into the material than a normal eddy current, as shown in equation (1).
Many distortions can occur in PEC inspection because the PEC contains all the frequencies and the penetration depth is very deep. In addition, the high-frequency pulse can be distorted by the coil and cable, and the high-frequency component decreases. Actual measurements show a maximum penetration depth of about 20–30 mm. The pulses typically have a 50% pulse width and are controlled to induce the eddy current in the pulse period. The pulse power (voltage or current) and pulse repetition rate (PRF) should be adjusted to fit the examination of the characteristics.

By adjusting the PRF and pulse power, as is done for ultrasound, pulse eddy current testing shows transient response signals. However, it is difficult to determine the penetration depth and thickness changes using these transient signals because they contain much noise. Moreover, the PEC scan speed is slow for eddy current measurement.

Figure 3 shows the PEC signal processing principles devised by the authors. As is shown, the voltage change over time is used for acquiring the PEC signal. The PEC signals from the coil are stored in memory by a program for time-sharing and displaying the PEC signal in a graph, as shown in Figure 3. A display unit connected to the measurement unit displays the resultant value being output from the measurement unit.

The phase (a value selected from an arbitrary location by time-sharing the measured PEC signal), frequency (a frequency value of the input PEC signal), and gain (a time axis range for the reflected PEC signal) of the PEC signal can be set. Although various types of information are obtained by inspecting the impedance signal, there is a need for technology to properly analyze the collected signal. The thickness, corrosion, etc. can be determined by analyzing the decay time of the maximum amplitude of the signal.

![Fig. 3 Pulsed eddy current signal acquisition](image)

Figure 4 shows the characteristics of the signal for PEC inspection in relation to various parameters. We can see that the most significant changes occur from lift-off. As seen in Figure 5, the PEC signals are converted by impedance conversion into lift-off signals, and these signals change based on the thickness.

From the PEC signal, as shown in Figure 3, we select the most suitable sampling of the signals from the two of them and convert the impedance display.

By adjusting various parameters, we can separate the lift-off signal from the signal changes in the thickness of the phase. An impedance analysis can be used in the signal analysis to determine defects or changes in the thickness of the sample.
Pulsed eddy current application

Figure 6 shows various PEC probes and the PEC test equipment.

PEC testing technology can be used to determine whether steel is present in the material below the probe. From Figure 7, it could be determined whether a 10-mm-thick piece of carbon steel existed under another 10-mm-thick steel plate, based on the impedance.
It could also be determined whether steel was present in the plate below the top steel plate. In Figure 7, the 10-mm-thick carbon steel could be detected under the 10-mm-thick plate based on the impedance. It was difficult to distinguish the presence of carbon steel under a carbon steel plate that was thicker than 15 mm.

In addition, the presence of aluminum could be determined under an aluminum plate. In Figure 8, a 5-mm-thick aluminum plate could be detected under another 5-mm-thick plate.

As shown in Figure 9, carbon steel specimens were processed to measure the corrosion. A sliding steel plate was fabricated that varied in thickness linearly from 2 mm to 20 mm.

An experiment was conducted using two methods, wherein an aluminum plate was measured below a carbon steel plate, and a carbon steel plate was measured below another carbon steel plate. As shown in Figure 10, the 2–20-mm-thick carbon steel plate was measured under an 8-mm-thick aluminum plate.
Fig. 10 Thickness measurement of carbon steel plate that varied in thickness from 2 mm to 20 mm under 8-mm-thick aluminum plate

As shown in Figure 11, we also measured the thickness of the carbon steel plate that varied in thickness from 2 mm to 20 mm under a 10-mm-thick carbon steel plate. In the above experiments, a sheet of paper was inserted into a 5-mm air gap between the steel plates, and there was a 5-mm lift-off between the probe and test plate in this test.

Fig. 11 Thickness measurement of carbon steel that varied in thickness from 2 mm to 20 mm under 10-mm-thick carbon steel plate

Discussion and Conclusions

This paper presented a method to measure the corrosion of a structure consisting of two layers by measuring the presence of carbon steel in the bottom plate.

The carbon steel in a 2–20-mm-thick plate could be inspected below a 10-mm-thick carbon steel plate or an 8-mm-thick aluminum plate. PEC techniques have emerged as a new measurement method, which can be applied to specimens that are difficult to inspect using conventional eddy current and ultrasonic testing. PEC inspection techniques will be applied to auto part materials and nuclear and thermal power plant boiler pipe inspection and oil and heavy and the field of heat exchanger tube inspection. This PEC method could also be used for corrosion inspection under insulation and heat treatment. Thus, research on this technology should continue, with the goal of improving the performance of the software and analytical methods.

References