Defects Sizing Using a Pulsed Eddy Current Testing Method for Local Wall-Thinning Evaluation

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Abstract: In nuclear power plants, because of flow accelerated corrosion and liquid droplet impingement there may happen local wall-thinning in the pipes. Recently, research of pulsed eddy current testing (pulsed ECT) method shows that it has promising capability of detecting and evaluating defects in deep area of specimen due to its rich frequency components and applicability of large electric current. This study discusses the feasibility of detection and evaluation of wall-thinning in thick-walled piping using pulsed ECT method. The content of this study mainly contains two parts. Firstly, capability of thickness evaluation of a stainless steel plate is investigated. Experiments and numerical simulation were carried out using an SUS316 austenitic stainless steel plate, respectively. A novel and more stable feature was extracted from the differential pick-up signal and was discussed for the thickness evaluation of a plate. Numerical and experimental results demonstrate that the thickness of a plate can be obviously sized from characteristics of differential signals. Secondly, capability of depth detection of a slot defect in a stainless steel plate is investigated under condition of small lift-off. In experiments, scanning signals were obtained and through analyzing the magnitude of peak value of differential signal and its spatial distribution, the depth of a slit defect can also be successfully evaluated.

Keywords: Local wall-thinning, Pulsed ECT, Magnetic sensor, Feature extraction, Sizing

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1. Introduction

In nuclear power plants, there may happen local wall-thinning on the inner surface of a pipe due to flow accelerated corrosion (FAC) and liquid droplet impingement (LDI) of the coolant inside the pipe. Because of the existence of thick insulators outside the pipe, inspecting the wall-thinning which is located at the inner surface of a pipe by ultrasonic testing method becomes very difficult. Pulsed eddy current testing (pulsed ECT) technology is one method developed in recent years [1, 2]. Because of its un-necessity of contact between the probe and the inspected specimen, also its rich frequency components and applicability of large electric current [3-5], pulsed ECT method may show promising capability of detecting and evaluating of wall-thinning in thick-walled piping with lift-off. As the first step of this study, the aim of this paper is to discuss the feasibility of detection and evaluation of large area wall-thinning and small area wall-thinning on the inner surface of a pipe using a pulsed ECT method with 1mm lift-off.

2. Pulsed ECT system

2.1 Specimens

To simulate the large area wall-thinning on the inner surface of a pipe, six AISI316 austenitic stainless steel flat plates with different thicknesses were prepared in our experiments. The size of the plates is various thicknesses: 2, 3, 4, 5, 7mm and 10mm, 100mm in length and width. The thickness of a plate is to be evaluated from the top surface of the plate.

To simulate the small area wall-thinning on the inner surface of a pipe, five AISI316 austenitic stainless steel flat plates with a slot defect were prepared in our experiments. The size of the five plates is the same, 120mm in length, 100mm in width and 10mm in thickness. A rectangular slot defect was arranged along the center line of the bottom side of the plate in the width direction. The width of the slot defect is 10mm, and the depth is 2.5, 5, 6, 7, and 8mm, respectively. The depth of the slot defect is to be detected from the top surface of the plate. The specimen was shown in Figure 1.

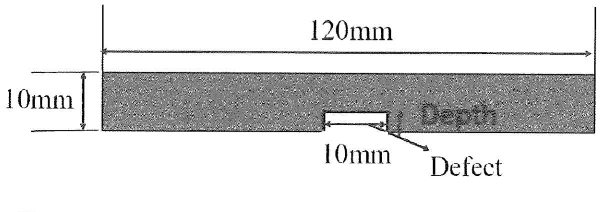

Fig.1. Plate specimen with a slot defect simulating small area wall-thinning

2.2 Experiment setup

Pulsed ECT experiment system we established consists of a function generator (WF1945, NF), a power amplifier (BP4610, NF), a scanning stage, an AD board and a PC etc. In the experiments, square wave pulse was generated from the function generator and then amplified by the power amplifier by which the output current could be controlled instead of the output voltage. Then the amplified current signal of square wave pulse was applied to the exciting coil as the exciting signal. A Hall sensor, one kind of magnetic sensor, is located at the bottom center of the exciting coil as the pick-up sensor, whose sensitivity is 5mV/G, and the manufacturer is Allegro Microsystems. Magnetic flux density of vertical direction is measured with the magnetic sensor. The pulsed ECT experiment setup was shown in Figure 2.

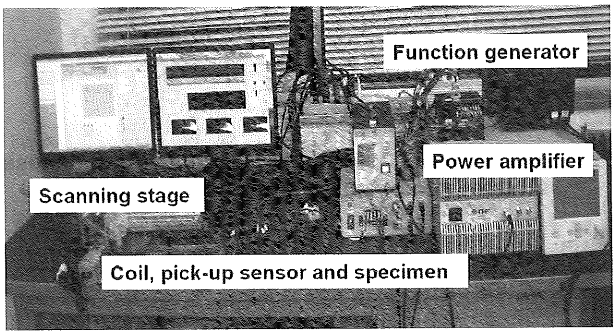

Fig.2. Pulsed ECT experiment setup

2.3 Simulation method

Finite Element Method was applied and ANSYS software was chosen as the simulation tool to simulate the transient eddy current problem. For the simulation with the specimens of the first group we can simply use the axisymmetric model because the plate-specimens are only various in different thicknesses and the exciting coil is pancake shape [6-9].

3. Results and discussion of large area wall-thinning detection

In this study, the thickness of a plate is to be evaluated from the pick-up signal using pulsed ECT method in experiments and simulation, respectively.

3.1 Original pick-up signal validation

In the experiment, lift-off is 1mm and the parameters of the exciting coil are inner diameter 30mm, outer diameter 40mm, height 15mm, wire diameter 1mm and turns 60. The pulse exciting current is exponentially decrease from high level to low level (see Figure 3) and the magnitude of the DC part is 7.8A, the period is 0.01s, the duty is 50%. The pick-up signal collected by the Hall sensor was averaged over 100 cycles of the transient output for duration of 1.0s, to reduce noise.

Typical 1-D transient outputs at the measured point of 4mm thickness plate and 10mm thickness plate are shown in Figure 4 for both experimental and numerical results. We can see that the experimental results and numerical simulation results match well quantitatively with each other. So the validity of our pulsed ECT experiment setup was verified.

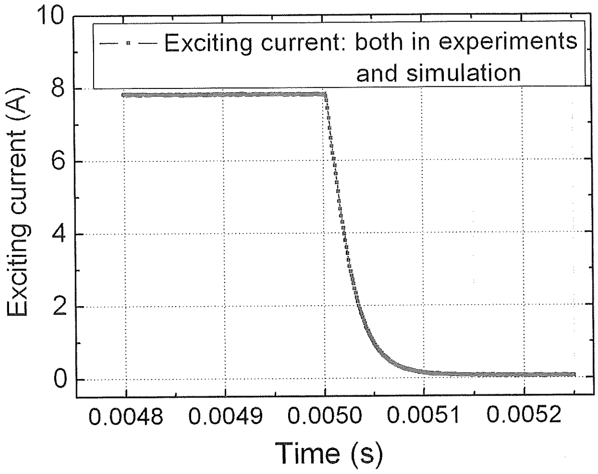

Fig.3. Exciting signals both in experiments and simulation

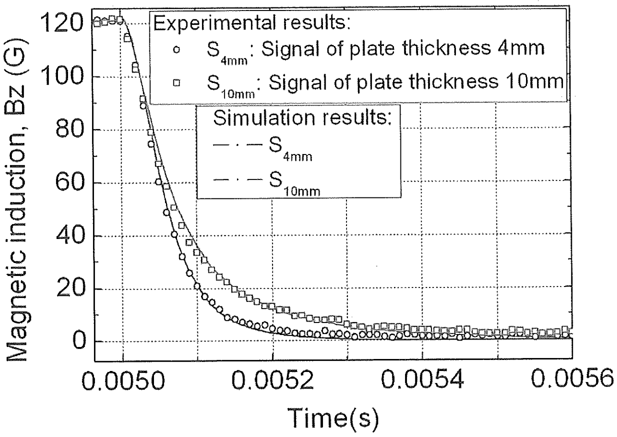

Fig.4. Comparison of original pick-up signals between experiments and simulation

3.2 New feature extraction

Figure 5 and Figure 6 show the experimental and simulation results of the differential signal of magnetic flux density based on the above pick-up signals, respectively, where the reference signal is the signal measured on a plate of 10mm thickness. And Figure 7 shows the typical conventional feature extraction from the differential signal, that is, peak value and peak time. Peak value is the magnitude of the peak point and peak time is the time to the peak point [10].

As we know the two conventional features extracted from the differential signal both are the property of the peak point, so we can simply imagine that they strongly rely on only the peak point, thus they should be easily affected by the occasional error in real application. Here another new feature was extracted from the differential signal, "area", which is the area between the differential signal curve and the time axis. We could imagine that even though the peak point was affected by the occasional error a little the area should not change a lot because it contains the information of all the points in pick-up signal, not only one point (peak point).

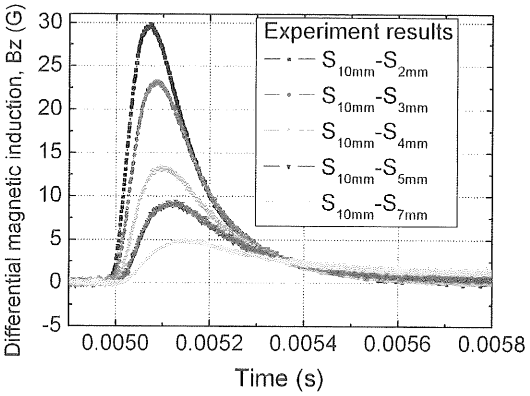

Fig.5. Differential signal of magnetic flux density in experiments

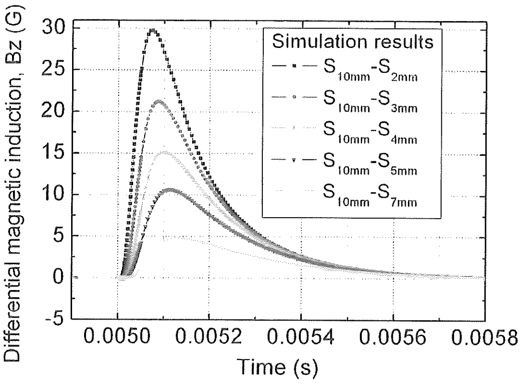

Fig.6. Differential signal of magnetic flux density in simulation

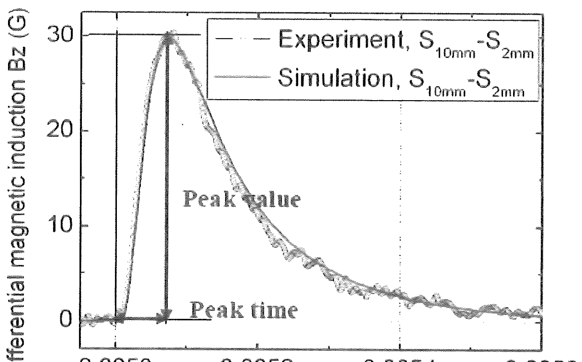

Fig.7. Typical conventional feature extraction in differential signal

Repeated experiments were carried out five times for every plate, the averaged signal was utilized as the experimental pick-up signal to avoid the occasional error which we mentioned above. The three features (peak value, peak time, area) were extracted from the experimental results and simulation results and shown in Figure 8, 9 and 10, respectively. We can see that all of them can give us good agreements with simulation results. Thus the thickness of a plate can be successfully evaluated from the characteristics of the differential pick-up signal.

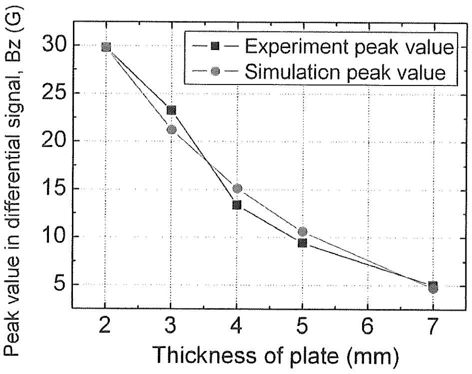

Fig.8. Relationship between peak value and thickness of plate both in experiments and simulation

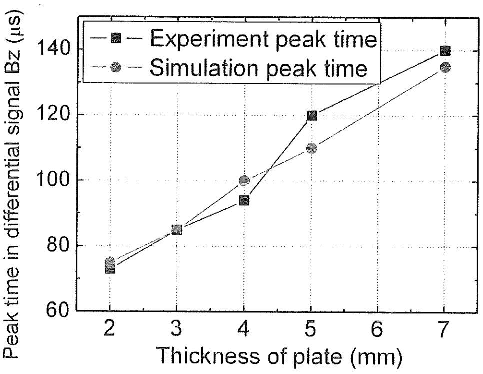

Fig.9. Relationship between peak time and thickness of plate both in experiments and simulation

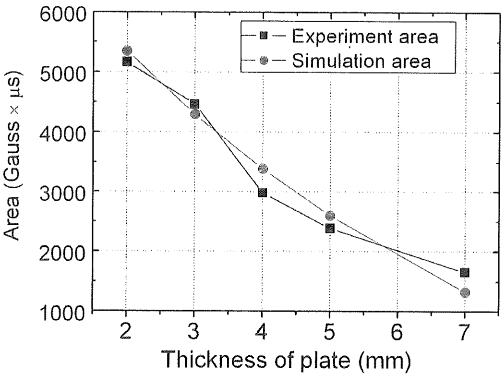

Fig.10. Relationship between area and thickness of plate both in experiments and simulation

3.3 Stability investigation of features

As we know, stability of the extracted features is very important for thickness evaluation in practical application. So here three features were extracted from the above five times repeated experimental results of every plate, respectively. Results of 2mm thickness plate were investigated to check the stability of the extracted features. Table 1 shows the values of the three features in every experimental result and their errors in which the value of mean square error divided by mean value was applied.

Table 1 Stability comparison of the three features in repeated experimental results

Evaluation items	Peak value (Gauss)	Peak time (μs)	Area (Gauss×μs)
Experiment 1	29.865	76	5182.9
Experiment 2	29.895	73	5172.0
Experiment 3	29.865	76	5161.8
Experiment 4	30.011	71	5130.2
Experiment 5	30.223	73	5161.8
Mean square error / mean value	0.51%	2.9%	0.38%

From Table 1 we can see that the error of peak time is the biggest, so peak time is the most not stable feature in the repeated experimental results. Inversely, the errors of peak value and area are very small, so they are relative stable features. Thus we could conclude that in practical application, if possible, feature of peak value or area had better been applied as the characteristic to evaluate the defect, not peak time.

4. Results and discussion of small area wall-thinning detection

In this study, the depth of a slot defect on the bottom side of a plate is to be evaluated from the pick-up signal using feature of peak value in experiments.

In the experiment, lift-off is 1mm and the parameters of the exciting coil are inner diameter 30mm, outer diameter 50mm, height 15mm, wire diameter 1mm and turns 129. The magnitude of the DC part of the pulse exciting current is 10A, the period is 0.02s, the duty is 50%. The pick-up signal collected by the Hall sensor was also averaged over 100 cycles of the transient output for duration of 2.0s, to reduce noise.

Specimen and inspection condition are shown in Figure 11. In experiments, scanning signal were obtained using scanning stage and the point which is 27mm far from the center of the defect was chosen as the origin. The bottom center of the exciting coil (also the position of Hall sensor locates at) started from the origin point and moved along the scanning direction where the interval of every step is 2mm.

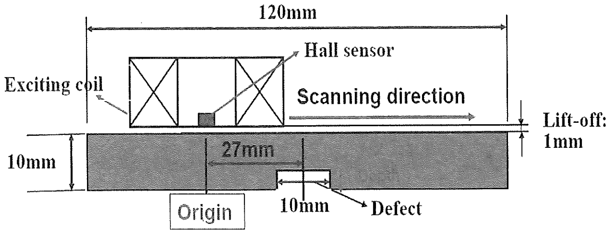

Fig.11. Inspection and scanning mode

The peak value at every scanning point was extracted from the differential signal where the reference signal is the signal of the first point (signal of origin point) to detect the slot defect of the plate. Figure 12 shows the results of five different specimens with different depth of slot defect. We can see that the positions of the absolute maximum value in all scanning signals are the same which are located at the center of the slot defect. In addition, the absolute maximum value of the scanning signal becomes larger when the depth of the defect becomes bigger. Figure 13 shows the relationship between the absolute maximum value of scanning signal and the depth of defect.

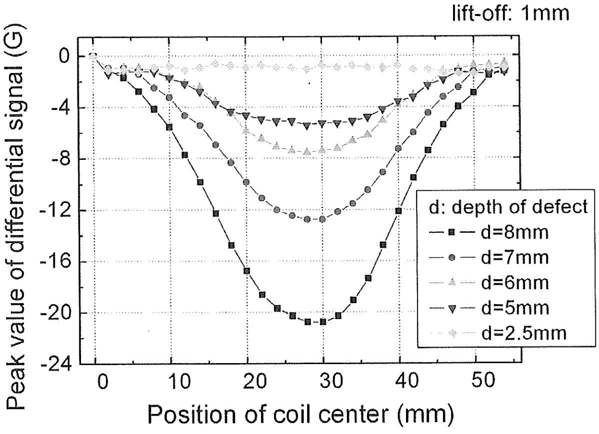

Fig.12. 1-D scanning signal of five different specimens

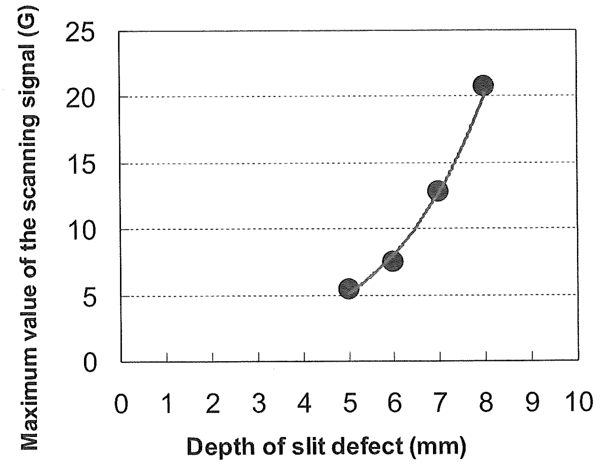

Fig.13. Relationship between the absolute maximum value of scanning signal and depth of defect

Thus we can conclude that the depth of a slot defect can be detected and evaluated through the relationship between the absolute maximum value of scanning signal and depth of defect.

Here another point that we need pay attention to is the defect of 2.5mm depth could not be detected because its peak value of defect signal is close to the noise level of Hall sensor which is about 1.0Gauss [11]. So for the future work, more sensitive magnetic sensor combined with corresponding novel exciting mode will be considered to increase the capability of detection of small defect in thicker specimen with bigger lift-off [12-13].

5. Conclusion

A novel and more stable feature was extracted from the differential signal as one new characteristic to evaluate the wall-thinning in pulsed ECT method. Numerical and experimental results demonstrate that the difference in the thickness of a plate (thinner than 10mm) and the depth of a slot defect in a plate (thickness is 10mm) can be obviously evaluated from the characteristics of the differential signals. So the large and small area wall-thinning of the pipes in nuclear power plants both can be detected using pulsed ECT method. For the future work, high sensitive magnetic sensor combined with corresponding novel exciting mode will be considered to increase the capability of detection of small defect in thicker specimen with bigger lift-off.

Acknowledgments

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