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Utilization of Lamp Lock-in for Wall-Thinned Defects Detection Using IR Thermography

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1. Introduction

Recently, the number of long-term aged nuclear power plants (NPPs) has increased. As a result, the problem of the NPP secondary system equipment also increased. For these reasons, the interest about NDT for checking the integrity of the major equipment is growing. The infrared (IR) thermography can detect the defects by analyzing the surface radiant energy from the object through real-time temperature-changing images. To detect the wall-thinned defects of the pipe inside precisely and quickly, it is most important to control the heating device. The IR thermography is expected to show a variety of applications in the field of NDT because it is much safer and faster than other techniques.

Through this study, we have developed the inspection technique that can detect the defects by using the lock-in technique in the IR thermography for inspection of pipes in the NPPs during the overhaul.

2. Theoretical Background

2.1 Infrared Thermography (IR)

All objects have their absolute temperature and they keep a constant temperature by the thermal equilibrium between absorbed energy and emitted energy.

$$\frac{dR(\lambda,T)}{d\lambda} = \frac{2\pi hc^2\lambda^{-5}}{e^{hc/\lambda kT} - 1} \qquad (1)$$

Plank's constant $h = 6.626\times10^{-34} J\cdot s$

Boltzmann's constant $k = 1.380\times10^{-23} J\cdot s$

Speed of light $c = 2.998\times10^{8} ms^{-1}$

Eq. (1) is an equation explaining the Plank's blackbody radiation theory and Eq. (2) is the Stefan Boltzmann's law. Eq. (2) is derived from Eq. (1).

$$\int_0^{\lambda} \frac{dR(\lambda,T)}{d\lambda} \qquad R_t = \sigma T^4 \qquad (2)$$

The Stefan-Boltzmann's constant is as follows:

$$\sigma = 5.67\times10^{-8} W/\left(m^2\cdot K^2\right)$$

The IR thermography uses the correlation of energy and temperature by measuring the amount of emitted energy. Therefore, we can measure the temperature through an IR camera by using the Plank's law and Stefan-Boltzmann's law.

2.2 Lock-in IR Thermography

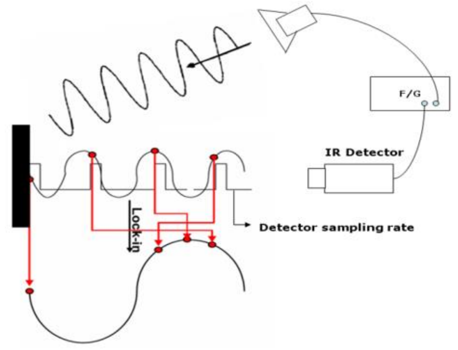


Fig. 1. Signal processing of IR thermography using lock-in

Fig. 1 shows the principle that the light source is incident on the object in the form of harmonic function via the function generator by using the lock-in IR thermography. The desirable phase and amplitude are calculated through signal processing by accepting the infrared energy which is incident on the object through the synchronized sensing elements. The penetration depth of light source can be expressed as a function of frequency and thermal diffusion coefficient as shown in Eq. (3), and then it can predict the penetration depth of light source.

$$\mu = \sqrt{\frac{\alpha}{\pi f}} \qquad (3)$$

In Eq. (3), a thermal diffusion coefficient is a detection limit frequency.

3. Experiment Methods

3.1 Heating Experiments

We have performed the experiments that detect the wall-thinned defects using the IR thermography by adjusting the power and distance of the heating device. The experiments were carried out at the 1m, 2m and 3m away from the pipe specimen to the heating device. And these were carried out at the 80% and 100% powers of the heating device for 1 minute.

3.2 Heating Experiment Using a Lock-in Technique by Function Generator

We have used a function generator to detect the wall-thinned defects in the pipe specimen through the lock-in technique. The experiments were carried out at the 1m, 2m and 3m away from the specimen to the heating device. Also, these were carried out at the 80% and 100% power of the heating device for 1 minute.

3.3 Heating Experiment Using a Lock-in Technique by LabView

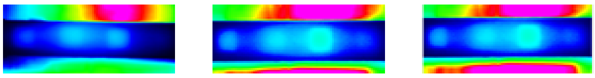
In carrying out the inspection for detection of wall-thinned defects during the NPP overhaul, the inspection device quipped with the Compact-RIO that is more portable and mobile than the function generator were devised and manufactured. And the continuous signals that are the same as the function generator were made using a LabView program. And the voltage signals were delivered continuously by adjusting the voltage output intervals precisely like the function generator. The experiments were carried out at the 1m, 2m and 3m away from the pipe specimen to the heating device. And also these were carried out at the 80% and 100% power of the heating device for 1 minute.

4. Experiment Results

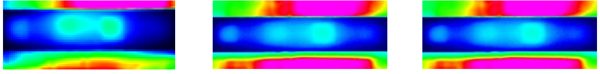
Fig. 2 are the IR images that show the wall-thinned defects of pipe specimen according to the distance and power of heating device. Through Fig. 2, we can see that the wall-thinned defects are most visible at 2m distance from the pipe specimen. Also, we can see that 80% power of the heating device is more visible than 100% power. Through Fig. 2, we can see that the adjustment of power and distance of the heating device is important to detect the defects.

Fig. 3 shows the experiment results using a lock-in technique by function generator. By using the lock-in technique, we can see that the location of the wall-thinned defects due to the thermal diffusion in the pipe specimen. Also, we can see that the defects are clearly detected from the IR camera by accepting the synchronized frequency signal. Through the results of Figs. 2 and 3, we can know that detecting the wall-thinned detects using the lock-in technique is more effective in detecting the location of defects than heating the pipe specimen continuously.

Fig. 4 shows the experiment results using a lock-in technique by LabView. The location of wall-thinned defects can be measured correctly when the lock-in technique is implemented through the voltage control using LabView without the function generator. As a result of the experiment, the wall-thinned defects in the pipe specimen were detected clearly at the 1m, 2m and 3m.

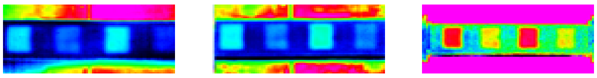


(a) 1m 80% (b) 2m 80% (c) 3m 80%

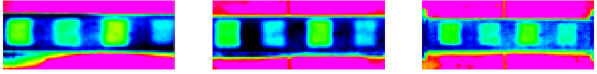


(d) 1m 100% (e) 2m 100% (f) 3m 100%

Fig. 2. Heating experiments

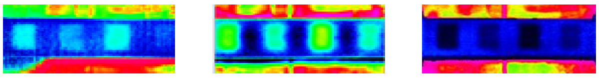


(a) 1m 80% (b) 2m 80% (c) 3m 80%

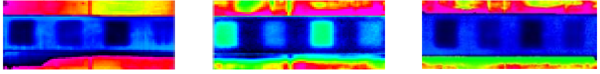


(d) 1m 100% (e) 2m 100% (f) 3m 100%

Fig. 3. Heating experiments using a lock-in technique by function generator.



(a) 1m 80% (b) 2m 80% (c) 3m 80%



(d) 1m 100% (e) 2m 100% (f) 3m 100%

Fig. 4. Heating experiments using a lock-in technique by LabView

5. Conclusions

In this study, lock-in techniques and output adjustment were applied to the heating device using the IR thermography in order to detect the wall-thinned defects in the pipe specimen. As a result of experiment, the location and size of the wall-thinned defects are detected well in case of using the lock-in technique than heating the pipe specimen continuously. By using the lock-in technique with LabView, an inspector can control the heating device through the computer.

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