In-Service Inspection of Wall-thinned Defects Using a Lock-in Technique of IR Thermography

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1. Introduction

Recently, the safety problem of nuclear power plants (NPPs) has emerged as a global concern. As a result, the secondary system equipment in long-term aged NPPs has been growing interest. For these reasons, NDT for checking the integrity of the secondary system equipment is performed. The infrared (IR) thermography is one of the NDT. It is possible for us to solve the problems of the existing NDT. IR thermography can detect without contact the wall-thinned defects in pipes. Also, IR thermography using a lock-in technique for inspection is much safer and faster than other techniques. It is expected to be able to accurately detect the boundary of the non-defect parts and the defect parts, and shows a high utilization in the industrial field. Through this study, we have developed the inspection technique that can detect the defects by using the lock-in technique in IR thermography for inspection of pipes in the NPPs during the normal operation.

2. Theoretical Background

2.1 IR Thermography

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

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

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

Boltzmann's constant $k=1.380546\times10^{-23}$

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

$$R=\sigma T^4 \tag{2}$$

Stefan-Boltzmann's constant is as follows:

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

Eq. (1) is related to Planck's blackbody radiation theory. And Eq. (2) is Stefan-Boltzmann's law. Planck's blackbody radiation theory shows the relationship between the wavelength, temperature, Boltzmann constant, Planck's constant, and light speed. The IR thermography uses the correlation of energy and temperature by measuring the amount of emitted energy. The IR camera can measure the temperature using the Planck's blackbody radiation theory and Stefan-Boltzmann's law.

2.2 Lock-in IR Thermography

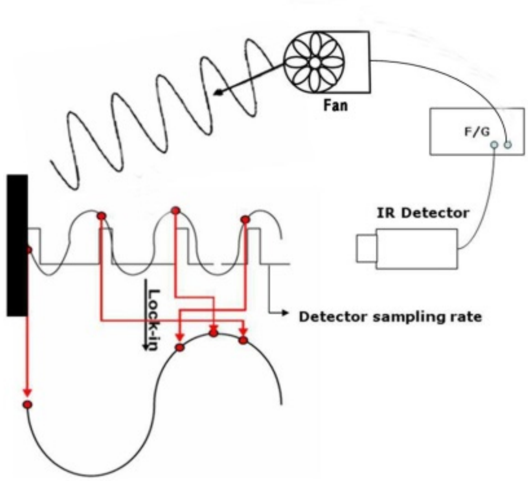


Fig. 1. Signal processing of IR thermography using a lock-in technique

Fig. 1 shows the principle that the cool wind 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 cooling can be expressed as a function of the frequency and the thermal diffusion coefficient as shown in Eq. (3), and then it can predict the penetration depth of cooling.

$$\mu=\sqrt{\frac{\alpha}{\pi f}} \tag{3}$$

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

3. Experiment Methods

3.1 Pipe Specimen

In this experiment, the pipe specimen was manufactured using the Shc.80 ASTM A106 Gr.B that is the actual NPP's material. The pipe specimen with defects generated artificially in the inner wall of the pipe was used.

3.2 Inner heating device

Fig. 2 shows the inner heating device for pipe specimen. The temperature of the pipe was kept at 150°C by using two thermal tapes.

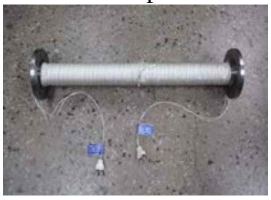


Fig. 2. Inner heating device

3.3 Continuously Cooling Experiment

We have performed the experiments that detect the wall-thinned defects using IR thermography by adjusting the distance and number of cooling fans. The experiments were carried out at 1m and 2m away from the specimen to the cooling device. The cooling experiments were carried out for 1 minute.

3.4 Cooling Experiment Using a Lock-in Technique by Function Generator

Fig. 3 shows the experiments that use a function generator to adjust the power of the cooling device for a lock-in technique. The experiments were carried out at 1m and 2m away from the specimen to the cooling device. The cooling experiments were carried out for 1 minute. The location and size of the wall-thinned defects are detected well in case of using the lock-in technique.

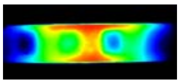
Fig. 3. Experiments with cooling device

4. Experiment Results

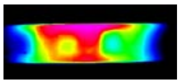
Fig. 4 shows the IR images that show the wall-thinned defects of pipe specimen according to the distance and number of cooling devices. Also, experiment images captured from using two cooling devices are more visible than those from one cooling device. From Fig. 4, we can see that the adjustment of distance and number of the cooling device are important to detect the defects.

Fig. 5 shows the experiment results using a lock-in technique by a function generator. By using the lock-in technique, it is found that there is a temperature difference in many defective parts of the pipe. Due to the temperature difference between the normal parts and the defective parts, the boundaries between the normal parts and the defective parts are clearly visible.

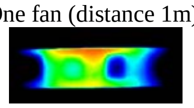
In Figs. 4 and 5, we can know that detecting the wall-thinned detects using the lock-in technique is more effective in detecting the location of defects than cooling the pipe specimen continuously.



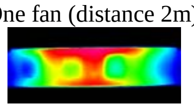
(a) One fan (distance 1m)



(b) One fan (distance 2m)

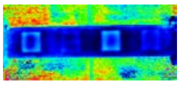


(c) Two fan (distance 1m)

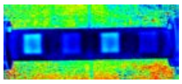


(d) Two fan (distance 2m)

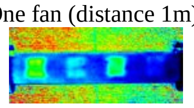
Fig. 4. Continuously cooling experiments



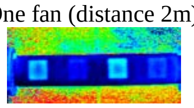
(a) One fan (distance 1m)



(b) One fan (distance 2m)



(c) Two fan (distance 1m)



(d) Two fan (distance 2m)

Fig. 5. Cooling experiments using a lock-in technique by function generator

5. Conclusions

In this study, a lock-in technique and power adjustment were applied to the cooling device for the IR thermography in order to detect the wall-thinned defects of the pipe specimen in a normal operation NPPs. According as the number of the cooling devices is increased and air volume transferred by the cooling device increases, wall-thinned defects inside pipes are more visible. By cooling the pipe using a lock-in technique in IR thermography, the boundary of the wall-thinned defective part is clear and the defect detection is easy. It is expected to detect the wall-thinned defects of piping during normal operation, to shorten the maintenance time of the NPPs, and to improve the work efficiency of the inspector.

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