On-Power Detection of Wall-Thinned Defects Using IR Thermography in NPPs

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1. Introduction

Recently, the number of nuclear power plants (NPPs) that are aging by long-term operations has increased. Accordingly, the number of operational interruptions has increased due to malfunctions of the NPPs secondary systems. These cases occur in the NPPs secondary systems with various structures by the fatigue, wall-thinned defects, corrosions and so on [1]. Of these problems, the wall thinned defects occur in the pipes by the diffusion of the corrosion with the flow of the fluids, and the defects frequently take place in the carbon steel pipes of the lower Cr contents. Periodic inspections are required for systematic management of the wall-thinned defects. In particular, they are also needed during the normal operations of the NPPs. There are many NDT techniques to detect the wall-thinned defects such as the UT, PT, ECT, MT, etc. These NDT techniques include the infrared thermography. This technique may solve the existing constraints of NDT by detecting the defects through observations of the temperature differentials on the object surface.

2. Theoretical Background

2.1 Infrared Thermography (IR)

When a specific target is cooled by the outside cooler, thermal diffusion on the target surface is interrupted by the defects inside the target. At this point, the temperature differential occurs on the target surface by the insulation caused by the defects. The IR thermography provides real-time images by scanning the temperatures of the target surface and then, converting it into the temperature [2]. So, this technique can measure the shape and location of the defects.

2.2 Theory

All objects have the temperature above the absolute zero ($0K = -273.15°C$) degree and emit the radiant energy corresponding to the temperature.

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

Plank's constant $h = 6.626 \times 10^{-34} J \cdot s$

Boltzmann's constant $k = 1.380546 \times 10^{-23}$

Speed of light $c = 2.998 \times 10^{8} ms^{-1}$

Eq. (1) is related to Planck's blackbody radiation theory. In Eq. (1), the simple relationship is established between the properties of blackbody radiation and the blackbody temperature. So, the temperature of blackbody can be obtained from the properties of blackbody radiation. The IR thermography provides the temperature image using the correlation between the temperature and detected energy.

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

Steffan-Boltzmann's constant

$\sigma = 5.67 \times 10^{-8} W / \left(m^2 \cdot K^2\right)$

In Eq. (2), T is the absolute temperature (K) of objects, which is given by the Kelvin. And R_t is the reflection intensity of the blackbody. The IR camera can measure the temperature using Eqs. (1) and (2).

3. Experimental Equipment and Methods

3.1 Specimen

In this study, a pipe specimen with processed defects in the inner wall of the pipe was used. To perform this study, the pipe specimen was manufactured using the Shc.80 ASTM A106 Gr.B material such as the actual NPP's material.

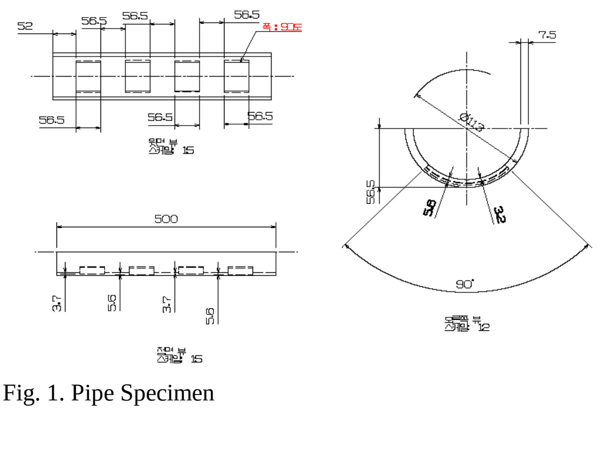


Fig. 1. Pipe Specimen

As shown in Fig. 1, the pipe specimen has the size of full-length (l)=500mm, thickness (t)=7.5mm and diameter (D_0)=113mm. The four defects of L/D_0=0.5 (L=56.5mm) are made artificially in the inner wall of the pipe specimen.

3.2 Simulation Methods

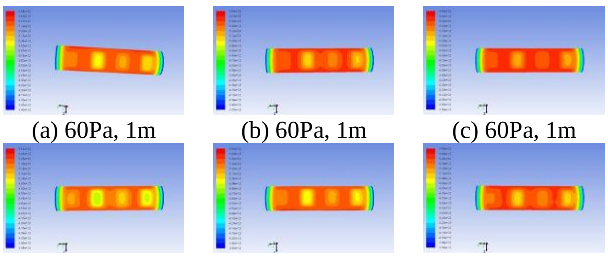
In this study, the fan type coolers were chosen as the cooling equipment. The simulation analyses were performed by the Ansys fluent program to find the optimal experimental conditions and the effects of the cooling equipment. The basic modeling of the simulation analyses was conducted with the pipe model and the cooling fan model in the X-Y-Z coordinated space. The pipe model was modeled with the same specimen properties as ASTM A106 Gr.B. And the defects were generated artificially with the same size of the pipe specimen. To describe the pipe of the actual NPPs, the initial temperature of the pipe model was maintained at $290^o C$. The simulations were performed by adjusting the distance between the cooling fan and the pipe model. The distance of the cooling fan was set at 1m, 2m, and 3m.

3.3 Experiment Methods

The temperature of the piping system in the NPPs secondary is maintained high during the normal operation period of NPPs. Thus, this experiment was performed at $95^o C$ by using the heating tape on the inside of the pipe specimen. The experimental equipment consists of the IR camera (FLIR Siver 480M), two types of fans, heating tapes and a PC. In this experiment, the distance between the pipe specimen and the IR camera was fixed at 1m, and the distance between the cooling fan and the pipe specimen was set at 1m, 2m or 3m.

4. Results

4.1 Simulation Results

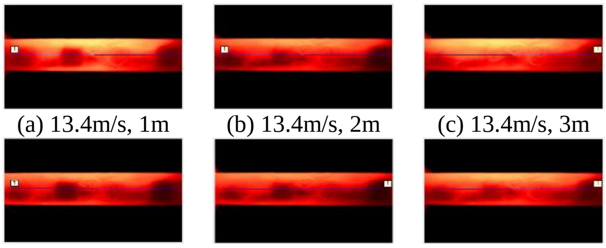


(a) 60Pa, 1m (b) 60Pa, 1m (c) 60Pa, 1m
(d) 100Pa, 1m (e) 100Pa, 2m (f) 100Pa, 3m

Fig. 2. Computer simulation results

Fig. 2 shows the simulation results according to the distance and intensity of the cooling fan model. In the images of the simulation results, the temperature distribution on the surface of the pipe model was blurred at the defect depth of d/t=0.5. However, the shape of defects became clear when the distance between the pipe model and cooling fan was short. In conclusion, the higher the cooling rate is and the shorter the distance between the cooling fan and the pipe is, the better the detection efficiency is.

4.2 Experiment Results



(a) 13.4m/s, 1m (b) 13.4m/s, 2m (c) 13.4m/s, 3m
(d) 14.9m/s, 1m (e) 14.9m/s, 2m (f) 14.9m/s, 3m

Fig. 3. IR images of defective pipe specimen

As shown in Fig. 3, the IR images were compared according to the distance between the pipe specimen and the cooling fan with intensity of the cooling fans. In the experiment result images, the temperature distributions at the surface of the pipe specimen were not clear at the defect depth of d/t=0.5. However, the defects with d/t=0.75 were clearly measured, when the pipe specimen and cooling fan were closer to each other.

5. Conclusions

In this study, the IR thermography technique was applied to detect the wall-thinned defects during the normal operation in the NPPs. To carry out this study, the pipe model and the pipe specimen were made of the Shc.80 ASTM A106 Gr.B material which is the actual NPP's material. And the size of the defects applied to the pipe specimen is the same as that of the pipe model of the simulation. The simulation shows that the closer the pipe and cooling fan, and the higher the intensity of the cooling fan model, the easier the detection of defects. Also, in the experiment with the simulation results, partial identification of the defects was possible. And the defects with d/t=0.75 were easily found when the distance between the pipe specimen and the cooling fan was as short as 1m. In conclusion, to find the defects in the normal operation of NPPs, the distance between the pipe and cooling equipment should be 1m and the intensity of the cooling equipment should be higher.

REFERENCES

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[2] G. Gaussorgurs, "Infrared thermography" Translated by S. Chomet, pp. 415-452, Champmam & Hall.London, 1994.