Nondestructive Image Detection of Cracks for a Nuclear Fuel Plate by Using Active Thermal Phase

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1. Introduction

Nondestructive crack detection is a key process for the safety insurance of the nuclear fuel plates which are widely used in a nuclear research reactor. Among nondestructive detection techniques, X-ray inspection technique and ultrasonic inspection technique using high frequency are widely used to detect internal cracks of a nuclear fuel plate at present.

Though X-ray inspection is fast and efficient technique by providing a crack image for whole specimen area, this technique hardly provides the delaminated crack information which should be detected. Ultrasonic inspection is also an efficient tool to detect internal cracks of materials. High frequency ultrasound based on the piezoelectric transducers is usually used to detect cracks of a nuclear fuel plate. Though it is useful technique, the inspection should be carried out by an immersion test in a water-tank and its signal is complex and it is time consuming technique because the inspection is scanned point by point in sequence for whole inspection area. A commercial scanning ultrasonic system using high frequency is usually adopted to detect cracks.

An alternative inspection technique to overcome the disadvantages of the high frequency ultrasonic inspection technique is needed. Especially, nondestructive imaging techniques of the internal cracks will be useful because it can be easily used in the field.

One of efficient nondestructive testing techniques is infrared thermo-graphic technique. Infrared thermo-graphic is a contactless optical imaging technique by detecting the invisible infrared radiation. Pulsed [1, 2] and lock-in [3] thermography are commonly used in thermo-graphic nondestructive evaluation techniques. The two techniques are distinctly different but are deployed in the inspection of similar components. In general, these techniques are suitable for the detection of shallow planer defects, e.g. delamination in composites or adhesion defect in surface coatings.

The surface of a specimen is instantaneously heated by using a flash lamp in pulsed thermography, and then the surface heat penetrates into the material. If there are internal cracks, heat-flow is obstructed. The pulsed thermography detects the flaws by using this heat-flow variation.

By contrast, active lock-in thermography technique periodically heats a specimen by modulating the lamp power. An intensity crack image and a phase crack image are acquired by extracting the intensity information and phase information at the periodic frequency, respectively [4-6].

The lock-in thermo-graphic technique usually provides an improved crack image compared to the pulsed thermography though it is time-consuming. A phase crack image is more widely used than the intensity because phase data is not depended on the thermal disequilibrium of the surface.

In this paper, active lock-in infrared thermo-graphic technique is adopted to try to detect an internal crack image of a nuclear fuel plate specimen. The experimental result of this new inspection approach is described in this paper.

2. Configuration of a Nondestructive Thermal Inspection System and Experiments

A block diagram of a configured active lock-in thermal inspection system is shown in Fig. 1. The system consists of a heater (halogen lamp) with a controller including a function generator, a Infrared camera and a computer.

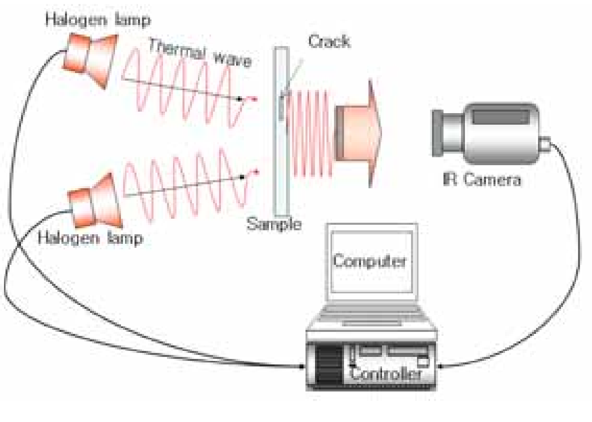

Fig. 1. Block diagram of a configured active lock-in thermo-graphic system.

Thermal wave is periodically generated from the halogen lamps whose intensity is controlled by the controller. The thermal intensity is sinusoidal pattern which is produced by the computer. The thermal wave will be propagated from the surface into the material of the specimen. The IR camera positioned at the opposite side of the specimen sequentially catches thermal images. The thermal phase come from the internal crack in a captured thermal image will be shifted when compared to the intact thermal signal because the thermal wave will be reflected by the crack.

A test specimen was prepared for the experiment as shown in Fig. 2. The material of the specimen is aluminum and its size is 120 mm x 35 mm x 2 mm. Three defects were made at the back side of the specimen and theirs diameters are 10 mm, 7 mm and 5 mm, respectively. Surface depth from the crack is 0.5 mm. The photo of the specimen is shown in Fig. 3.

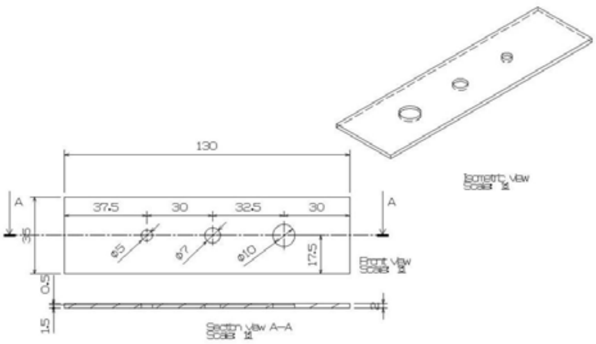

Fig. 2. Dimension of an aluminum plate specimen for the nondestructive inspection test.

Fig. 3. Photo of an aluminum plate specimen.

A thermal intensity of the sine pattern coming from the halogen lamp is selected by the computer. The used periodic frequency was 0.1 Hz and the maximum thermal power of the lamp was 120 W. The thermal images were captured during 50 periods with the sample rate of 6 Hz.

The Detected phase image is shown in Fig. 4. The opposite-side defect with its diameter of 10 mm was clearly detected as shown in the experimental result of the Fig. 4. The defect of its diameter of 7 mm was also detected but its distinctness was lower than the defect of 10 mm. Also, the defect of 5 mm diameter was also detectible but the distinctness was lower than the others. The decreasing of the detection capability for the smaller internal defects will be caused by the spread of the thermal energy during propagating from surface into the material.

As we can see from the experimental results, the general lock-in thermo-graphic technique was efficient for the internal crack with larger diameter of 5 mm. To improve the detection capability of the system, more precise IR camera and high powerful heating device will be needed and also optimum signal processing technique for the nuclear fuel plate is needed to be developed.

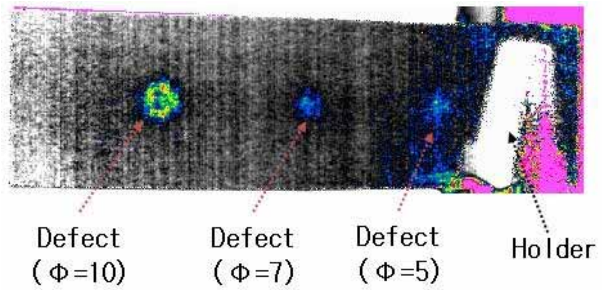

Fig. 4. Detected phase image from an aluminum plate specimen.

3. Conclusions

To see the detection capability of the infrared thermography for the internal cracks of the nuclear fuel plate, active lock-in thermo-graphic technique was applied. Phase shifted data was used to detect internal crack images from a specimen because the phase information was robust for the thermal disequilibrium on the surface. As the experimental results, the defects of diameters from 10 mm to 5 mm were detectible.

For further research, improving techniques including efficient heating device and optimized signal processing technique are needed to detect small internal cracks.

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