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Nondestructive Imaging Inspection of Defects for a Nuclear Fuel Plate by Using an Active Laser Interferometer

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1. Introduction

Most research reactors have adopted the use of plate-type nuclear fuel, which consists of a fuel core in aluminum alloy. The production quality of nuclear fuel is an important part for an efficient and stable generation of thermal energy in research reactors. Thus, a nondestructive quality inspection for the internal defects of plate-type nuclear fuel is a key process during the production of nuclear fuel for safety insurance. Nondestructive quality inspections based on X-rays and ultrasounds have been widely used for the defect detection of plate-type nuclear fuel [1-2].

X-ray testing is a simple and fast inspection method, and provides an image as the inspection results [1]. Thus, the testing can be carried out by a non-expert field worker. However, it is hard to detect closed-type defects because the X-ray image is made from the density differences of the materials. Thus, an X-ray inspection is usually used for inspection of the filling status of nuclear fuel in aluminum alloy.

Ultrasonic testing is a powerful tool to detect internal defects including open-type and closed-type defects in plate-type nuclear fuel [2]. The testing can also provide thickness information for each internal plate of the fuel. A high frequency ultrasonic signal of over than 20 MHz is usually adopted because the thickness of each plate in plate-type nuclear fuel is about a millimeter to sub-millimeters thin. Thus, the inspection process is complicated because an immersion test should be carried out in a water tank. It is also a time-consuming inspection method because area testing is based on the scanning of the point-by-point inspections. In addition, this testing method needs to be carried out by an expert since the detection capability is greatly dependent on the inspector's knowledge.

In this paper, an optical imaging technique using an active laser speckle interferometer with periodic thermal power was developed to visually detect internal defects. The laser speckle interferometer is an optical technique used to measure micro changes in the surface topography [3]. This method is sensitive to very small displacement at a resolution of nanometers by superposing the speckle patterns of two different object states.

The information of deformation difference among intact areas and defect areas has been widely used for the detection of internal defects in plate specimens [3]. The phase information has been also used when the phases of frequency components in displacement variation among intact areas and defect areas are different during periodic deformation of plate specimens [4].

The developed active laser interferometer measures an interference image, which is a micro deformation image of a specimen surface including the internal defect information. Thus, the inspection can be carried out by a non-expert field worker. Here, the surface deformation is induced by a heater supplying thermal wave with the periodic sinusoidal intensities. The inspecting images can be displayed on a monitor in real time, and visual images including internal defect shapes after signal processing to reduce the noises can also be displayed. The experimental results using the developed active laser interferometer to detect the internal defects of a plate-type nuclear fuel specimen are described in this paper.

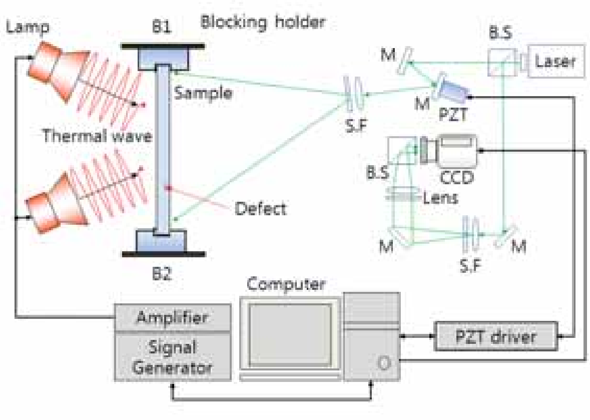

Fig. 1. Block diagram of a configured active laser interferometry inspection system.

2. Configuration of a Nondestructive Laser Interferometry Inspection System and Experiments

A block diagram of the developed noncontact imaging inspection system using an active laser interferometer with a thermal wave is shown in Fig. 1. The noncontact imaging inspection system was configured using two halogen lamps with a driver (DDS 5600, LEVITON MFG. co) controlled by a signal generator, a testing specimen held by a blocking holder, a digital speckle pattern laser interferometer (CW laser: 532 nm, 100 mW, Cobolt Samba™ 150) with a phase control driver (E-665.XR, LVPZT-AMP, PI) and a main control computer.

As shown in Fig. 1, the deformation shape of the specimen surface will vary according to the applied thermal power at the back side of the specimen. The thermal wave is generated by two halogen lamps driven by an amplifier. The intensity of the thermal wave is a periodic sinusoidal pattern controlled by a signal generator. The digital speckle pattern interferometer acquires a deformation interference image for the front surface of the specimen. The deformation interference image is an interference image between a reference laser beam and signal laser beam. As shown in Fig. 1, the reference laser beam reflected at the beam splitter (BS) goes into the CCD camera after passing through a mirror (M), a spatial filter (S. F), a mirror (M), and a focusing lens. The signal laser beam reflected from the front surface of a specimen goes into the CCD camera after passing through the beam splitter (BS), mirrors (M), and a spatial filter (SF). Here, the phase of the signal beam can be shifted using by using a piezoelectric transducer (PZT) controlled by a computer. Internal defect information is contained in the acquired interference image because the deformation difference is caused by the reflection at the internal defects of the thermal wave. An extracted deformation image including internal defect information will be produced after signal processing of the laser fringe images by the computer.

As shown in Fig. 1, a specimen was held by a blocking holder supported by spring force in the length direction of the specimen. Here, the specimen is freely movable in the thickness direction, but the movement is not free in the length direction when thermal power is applied. This blocking holder will increase the detection capability of the internal defect information by enforcing the strain increase to the defects.

A testing specimen was prepared for the experiments using noncontact optical imaging inspection for plate-type nuclear fuel. A tungsten plate with a similar density was used instead of uranium nuclear fuel. In a common structure of plate-type nuclear fuel, a plate-type uranium core is placed at the center of an aluminum alloy plate. The thickness of the used tungsten plate was 1.0 mm, and the thicknesses of the aluminum alloy at the front and back side were 0.5 mm, respectively. Three plates were bonded by metal paste except two delmaination-type defect areas. The sizes of the two delamination-type internal defects were 5.0 mm x 5.0 mm and 3.0 mm x 3.0 mm, respectively.

A periodic thermal wave with sine pattern intensities was applied to the specimen. The shape of the specimen will be periodically varied in proportion to the thermal power. To obtain a relative deformation shape, a reference phase image was extracted by a digital laser speckle interferometer.

The inspected image for the internal defect area is shown in Figs. 2 and its normalized image for the delamination areas is shown in Fig. 3.

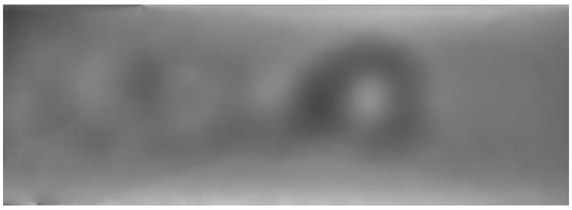

Fig. 2. Inspected image for the internal delaminations of a plate-type nuclear fuel plate.

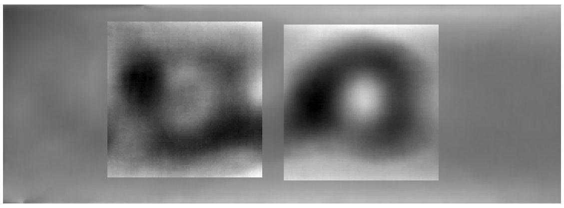

Fig. 3. Normalized image for the inspection defects of a plate-type nuclear fuel plate.

3. Conclusions

In this paper, an active digital speckle pattern interferometer was developed to visually detect internal defects for a plate-type nuclear fuel. The developed nondestructive noncontact imaging inspection system tried to detect internal closed-type defects, especially delamination defects, of a plate-type nuclear fuel specimen, where such defects should be detected in production process for safety insurance.

As the experimental results, we confirmed that the developed active laser interferometer system will be a efficient noncontact inspection tool for the nondestructive inspection of plate-type nuclear fuel production.

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