Study of different types of underwater measurement methods of physical shape of inner shell for JRTR

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ABSTRACT

After the start of the operation of research reactors, the radiation from reactor core will cause a deformation of the core structures. The reactor core structures especially the inner shell should be inspected as one of in-service inspections to conform the structural integrity. A study of the different methods for the measurement of physical shape of the inner shell for Jordan Research and Training Reactor (JRTR) was conducted. Four methods were studied and compared to find a few suitable ways for measuring the deformation of the inner shell. These methods are laser diode scanner, linear variable displacement transformer, eddy current, and dial gauge. The comparison was based on the workability of these methods under the effect of the measuring conditions. These measurement conditions includes: remote operability of the measurement tools in the pool water, radiation effects on the tools, weight and size of the tools, measurement accuracy, cost, measuring time, etc.

1. Introduction

Jordan Research and Training Reactor (JRTR) is an open pool type 5 Mwt nuclear research reactor. This reactor is under construction now. JRTR will be used for nuclear applications such as nuclear researches, isotopes production, neutron transmutation doping (NTD), training of engineers and scientists… etc. The core called "inner shell" made of Zircaloy. According to JRTR core will be deformed in radial direction by neutron irradiation. The core configuration and deformation measuring points are shown in figure 1.0. The deformation measurements of the reactor components is very important for reactor operations. The deformation of the components could lead to the uncertainty of the component to meet its functional requirements. This paper discusses and compares a few suitable measurement methods for the deformation measurement of inner shell of JRTR. The reactor core shall be inspected as one of in-service inspection to confirm the structural integrity. To measure the deformation of JRTR core, we have to take into account the dimensions of the reactor core to choose a suitable measurement sensor. The first part of the study presents an analysis among four methods that could be suitable for deformation measurements of JRTR. The analysis is focused on the workability of the methods under the effect of the measuring conditions; the depth of the measurement in the pool, radiation effect on the tool, weight and size of the tool components and the measurement accuracy. In this study, we are focused on four sensors such as dial gauge, Linear Variable Displacement Transformer (LVDT), eddy current, and Laser rangefinder scanner. In the second part in this paper, we suggest that Jordan Atomic Energy Commission (JAEC), the owner of the reactor, choose one among four types of sensors.

There are a few ideas of measuring deformation of the core applied in some nuclear research reactors around the world. In our study, we have studied HANARO research reactor in South Korea. The measurements of core deformation in HANARO use a dial gauge method. We have tried to find another suitable method to be used in JRTR for same purpose, considering different factors that will play an important role in deciding the most suitable method.

2.0 Operating Principles

The first principle of the dial gauge method is a mechanical method with a direct contact between the target surface and the sensor (dial gauge). The second principle is electrical measurement. This principle is applied to the eddy current method using electromagnetic field impedance and to the LVDT converting a mechanical displacement to an electrical output voltage.

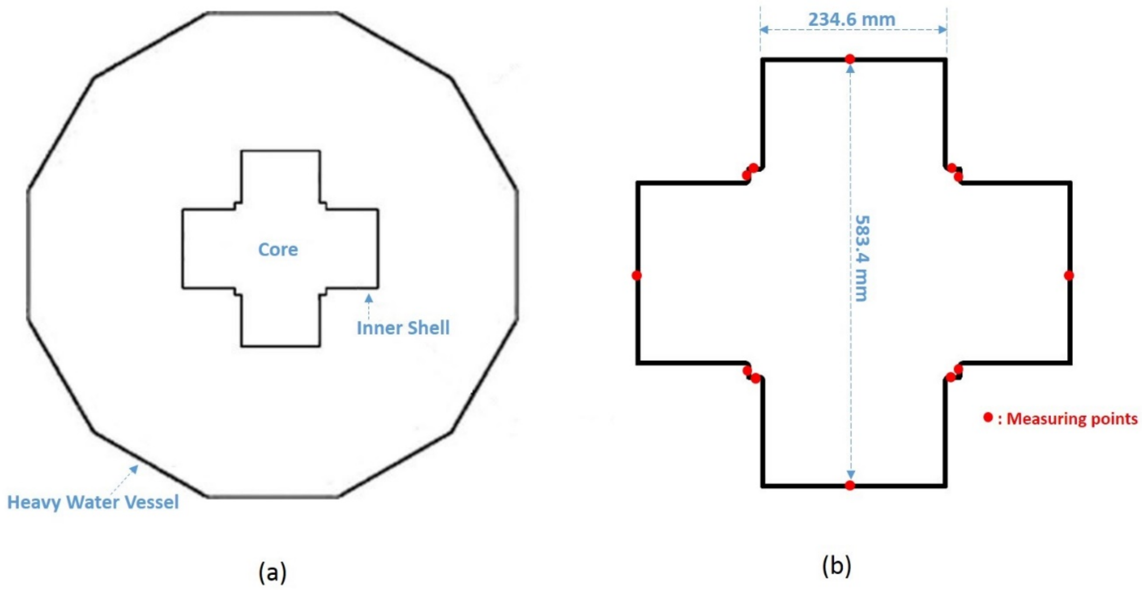

Fig 1. (a) Plan View of JRTR reactor core, (b) core dimension and deformation measuring points.

The third principle is a laser rangefinder which uses a laser triangulation. The laser beam emits to the target then the angle of the reflected beam from that target is measured with the collection by a special high-resolution camera.

2.1 Mechanical Method

The mechanical method measures the surface profile of a target by measuring discrete points on the surface of the target using a contacting sensor, dial gauge.

2.1.1 Dial Gauge

The dial gauge is a probe indicator typically consist of dial and needle to measure the deformation of the target. The probe loaded by a spring makes the needle to move on the dial to show the result. The results are collected manually and visually by an underwater video camera.

2.2 Electrical Method

2.2.1 Eddy Current Sensor

The eddy current sensor is an electrical sensor. An alternating current formed in the coils of the sensor creates an electromagnetic field directed to the surface of the target that induces an alternating current called "eddy current" at the surface of the target. Eddy current creates an opposing magnetic field that resists the electromagnetic field generated from the coils. The interaction of the generated and opposing fields depend on the distance between the probe and target. The sensor detects the change in the interaction field and produce a voltage output.

2.2.2 Linear Variable Displacement Transducer

The linear Variable Displacement Transformer (LVDT) is an electromechanical sensor which converts the mechanical linear displacement through the sensing probe to electrical signal. Thus, the displacement is proportional to the voltage output produced. LVDT can be manufactured to be radiation resistant as well as submersible.

2.3 Laser Rangefinder Measurement System

The laser rangefinder measurement is considered as a new method to measure the profile for underwater structures by two types of emitting lights; photons and waves. The rangefinder measurement depends primarily on collection of the large amount of points from the surface of target.

Laser triangulation is a method which uses more than one light patterns such as spot, line and grids emerged at an angle onto a target to obtain ranged information [1]. The system consists of laser, detector and lens that focus the beam to the detector. Usually the detector is a high-resolution video camera. The laser source emits a light on the surface of the target then the beam reflected from the surface to the detector through the lens. Reflected light angle and distance are calculated then the deformation of the target surface is analyzed and measured using special software that create 2D and 3D image for the target [2]. Different types of sensors used are transmitters such as laser diode, sonar, holographic and radar.

3.0 Comparison study

The dial gauge is used for reactor core deformation measurement in HANARO in Korea. While the Laser diode scanner is used widely in PWR and BWR nuclear reactors with different types of measurements. LVDT and eddy current sensors are also used in the reactors but maybe not for measuring the deformation of the core yet.

There are comparisons among the methods based on; measurements accuracy, workability underwater, workability in radiation field, sensor dimension and weight, measuring and data collection time, and sensor cost.

All the four sensors are good enough in accuracy of the measuring. The dial gauge usually has an accuracy of 0.01 mm. LVDT usually has a linearity error equal to 0.10% - 0.25% of full stroke [3]. Eddy current sensors have a linearity between 0.20% - 0.25% of full stroke [4], for a short range measurement like in JRTR inner shell. This error is relatively low and would be acceptable specially for the measurement range from 3.0 to 6.0 mm for each LVDT and eddy current sensor. Laser scanner has a high accuracy for underwater measurements. The company American Newton offers a special NM200UW laser scanner which operates by triangulation method. NM200UW has many applications for PWR and BWR nuclear reactors with an accuracy of 0.0127 – 0.0178 mm [5].

Talking to workability in underwater and radiation environment, these factors are highly level of importance. Radiation will affect and disturb the result of the sensors if they are not nuclear grade material to withstand the radiation. Especially gamma radiation is our concern in this study. The dial gauge usually well withstands the radiation because it's a fully mechanical sensor. The dial gauge also works properly underwater without any problem or malfunctions. The LVDT sensor works in underwater applications very well, and new generation of LVDT's that is made especially for nuclear reactors have the submersible features in addition to radiation resistance. In addition, the eddy current sensor has a high resistance to radiation and works properly in underwater applications. The laser diodes have been developed to have good workability in underwater applications. The laser scanner with high-resolution video camera as detector made from nuclear grade material could be very good choice for deformation measurements inside nuclear reactor. NM200UW laser scanner withstands radiation level up to 5000 R with no loss of effectiveness [5].

Another factor is the size of the each sensor. This term could not form a serious problem since the companies offer different sizes and dimensions. Due the limited dimensions of JRTR we have to choose a small sensor. As shown in above figure 1.0, the dimension of the core is small. The weight of sensor may affect the design of the sensor-mounting device. Dial gauge and LVDT considered as light sensors. The dial gauge weight about 100 g while the LVDT weight varies from 100 g – 500 g. The eddy current sensor usually has a very small size about a few millimeters and weigh about a few grams. NM200UW laser scanner has comparatively high weight which is about 3.5 kg in air and 1.0 kg in water but still accepted for JRTR.

The measuring time and data collection method are also important for time saving of in-service inspection. The dial gauge method needs about an hour for every vertical line because of manual reading of the dial by an underwater camera. In JRTR we need about 12 hours to measure for the 12 vertical lines excluding the replacement time of the sensor for each measurement line. The LVDT, eddy current, and laser scanner take less time because of automatic storage of measured data to a computer system.

Another important factor is the cost of the sensor. The dial gauge is not so expensive. One dial gauge costs about 100 USD, maybe a little more but still not expensive. The LVDT sensor usually costs from 700 - 1500 USD which is not so expensive, but if it is made from nuclear grade material to resist the radiation and made from a special material to resist the extreme environment conditions, the cost will be higher but still acceptable and with range of 3000 – 5000 USD for the sensor. The eddy current sensors slightly more expensive than LVDT but still acceptable. The laser diode is considered to be highly costly method, since it use laser diode as source of light and special highly resolution camera manufactured from nuclear grade material which makes the price so expensive. The cost of laser scanner with the software reaches about 200 thousands USD.

4.0 Discussion and Future work

Following table summarizes the comparison of the three methods.

Feature \ Sensor	Dial gauge	LVDT	Eddy current	Laser scanner
Accuracy	**High**	**High**	**High**	**High**
	~ 0.01 mm	~ 0.1% of full stroke	~ 0.2% of full stroke	~ 0.01 mm
Submersible	**High**			
	Withstands easily reactor pool pressure which equal 2.0 atm.			
Radiation resistant	**Mild Resistance**	**Mild Resistance**	**Mild Resistance**	**High Resistance**
	Up to 10^7 rad	Up to 10^7 rad	Up to 10^7 rad	
Dimensions	**Small**	**Medium**	**Small**	**Large**
	smaller than 70 mm	Around 150 mm	smaller than 70 mm	bigger than 150 mm
Weight	**Light**	**Medium**	**Light**	**Slightly Heavy**
	~ 100 g	~ 100 g – 500 g	Less than 50 g	Around 1.0 Kg
Contact with target	**contacting**	**contacting**	**Non-contacting**	**Non-contacting**
Data Collection	**Manual**	**Automatic**	**Automatic**	**Automatic**
Cost	**Low**	**Medium**	**Accepted**	**High**
	~ 100 USD	2000 – 5000 USD	5000 – 10,000 USD	~ 200,000 USD

Tab 1: Comparison conclusion among three deformation measurements methods

We think that the dial gauge, eddy current sensor, and LVDT are the most preferred methods considering all the conditions. The eddy current and LVDT methods cost a little more than the dial gauge method, but they are more convenient and reliable for the data collection during measurements. The working time for the measurement includes the removal of fuels and beryllium reflectors from the core, installation of the special tool with a sensor mounted, measurement, changing of the special tool to other position, reloading of the fuels and beryllium reflectors. Therefore, the measurement time itself is a small portion of total working period. The eddy current has an advantage that the sensor can be used for other measurement applications such as fuel rod oxidation inspection, checking components crack, components position measurement and local alignment of components.

A few special tools will be developed in near future for the deformation measurements not only for the inner shell but also for the beryllium reflectors in future. The development consists of selection of a specific sensor, design of sensor guide and mounting structure, and the procedures for the measurements.

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