Study on Poolside Inspection Technology for Pressurized Water Reactor Fuel Assembly

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Abstract：In this paper, the poolside inspection technology will be introduced through describing the underwater inspection methods. Each inspection method will be discussed and analyzed. Inspection technology mainly including visual testing, dimension measurement and eddy oxide measurement. This inspection technology has been successfully used for surface state inspection, irradiation growth and oxide layer thickness test of fuel assembly. And the necessary basis is provided for the irradiation stability and integrity of pressurized water reactor fuel assembly.

Key Word：pressurized water reactor fuel assembly, irradiation, poolside inspection technology

1　Introduction

Pressurized water reactors (PWR) have been widely used all over the world. The fuel assemblies are the power of reactor. The fuel rods may be damage when nuclear power plants at high burnup, long cycle water chemistry, low leakage and high power peak factor conditions. In order to identify the cause of fuel rods damage, the world's nuclear countries usually use the pool inspection methods which including underwater visual inspection, dimension measurement, eddy current testing, ultrasonic leak detection and other works to find which one of fuel assemblies damage and which one of fuel rods breakage in spent fuel pools. And then the fuel assemblies will be reconstituted and fuel rods will be transported to hot cell for destructive testing [1-7].

Poolside inspection (PSI, or underwater inspection) which using water as radioactive shielding is an important part of post irradiation examination(PIE). PSI techniques usually include sipping leak inspection techniques, visual inspection techniques, dimension measurement techniques, oxide thickness measurement techniques, ultrasonic leak detection technology and fuel reconstitution technology. The non-damaged fuel assemblies inspection techniques which include visual inspection techniques, dimension measurement techniques, oxide thickness

measurement techniques will be discussed in this paper.

PSI techniques which have been widely used in radiation effects research, new fuel assemblies research and development. PSI as the routine examination have been developed for decades in nuclear developed countries, and the continuous support has been given for new fuel assemblies research and nuclear power plants safe operation. There is still a long way to go for PSI techniques in China. According to study the PSI techniques, the complete detection capabilities will be formed and the road which China's peaceful development of nuclear energy will become wider and wider.

2   Poolside Inspection Techniques

2.1   Underwater Visual Inspection Technology

Visual inspection is the most direct and important method for stability and integrity inspection of post irradiation fuel assemblies, and the corrosion and obvious deformation of irradiated fuel assemblies will be determined. Underwater visual inspection technology which using underwater camera mainly researches the overall significant deformation of fuel assemblies, visible defects and damage, surface condition of fuel rods, sediment attached and so on. Typical photographs of underwater visual inspection are shown in Fig.1.

a) Overall Appearance   b) Grid Appearance
Fig.1 Underwater Visual Inspection

2.2   Underwater Dimension Measurement Technology

Underwater dimension measurement technology includes image measurement and LVDT measurement technology. Image measurement technology mainly researches length, bending and torsion of fuel assembly, shoulder gap and rod gap (Fig.2); LVDT measurement technology mainly researches dimension of rod diameter and grid width

(Fig.3). Through underwater dimension measurement technique research, the fuel assemblies will be identified whether or not return reactor core or reconstitution.
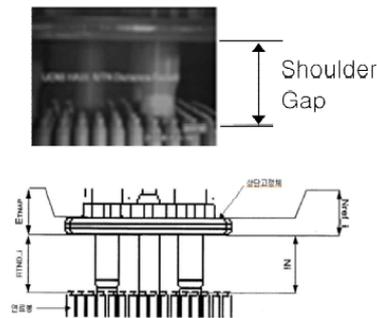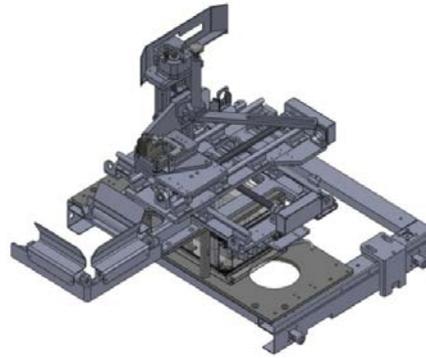

Fig.2 Image Measurement   Fig.3 LVDT Device

2.2.1　Image Measurement Technique

Image measurement technique is a method which based on video and calibration. The actual position of fuel assembly is corresponded to encoder value by calibration, and the underwater camera is used for image acquisition. According to the actual position corresponds to the position of ruler and pixel corresponds to the position of encorder, the fuel assembly grids image is converted into digital video signal and the measure results are achieved[8].

2.2.1.1　Fuel Assembly Length

The purpose of length measurement is to evaluat the irradiation growth of fuel assembly. The main content are the total height of fuel asembly, grid gap and so on.

The ruler is used to calibrate the encoder, the crane is used to lift fuel assembly, and the video is achieved by camera moving and focus on images from top to bottom of fuel assembly. The length of assembly is calculated, the measured data and the curve are shown in Fig.4.
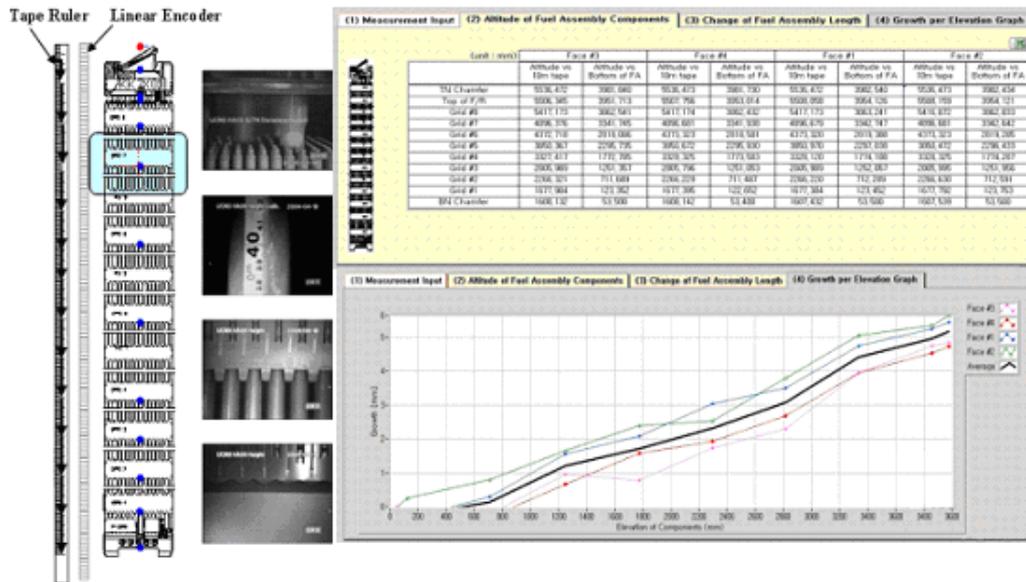
Fig.4 Fuel Assembly Length Measurement

2.2.1.2 Fuel Assembly Bow

The bending of fuel assembly may cause fuel rods damage through interference between assemblies. The bending amount and maximum bending parts of fuel assembly are mainly contents of measurement technique, and it is an improtant indicator for bending properties of irradiated fuel assembly. Fuel assembly bow is defined as the maximum difference between distance from the vertical line to nozzles and the distance from the vertical line to the center of grids. The bending on four faces of fuel assembly are obtained and the maximum is the assembly bending.

The camera focus position is selected on top nozzle of fuel assembly and vertical line. The pixel values which calculate the image distance from the vertical line to nozzles and grids are achieved. The measurement data and the curve are shown in Fig.5.

Bow (mm)

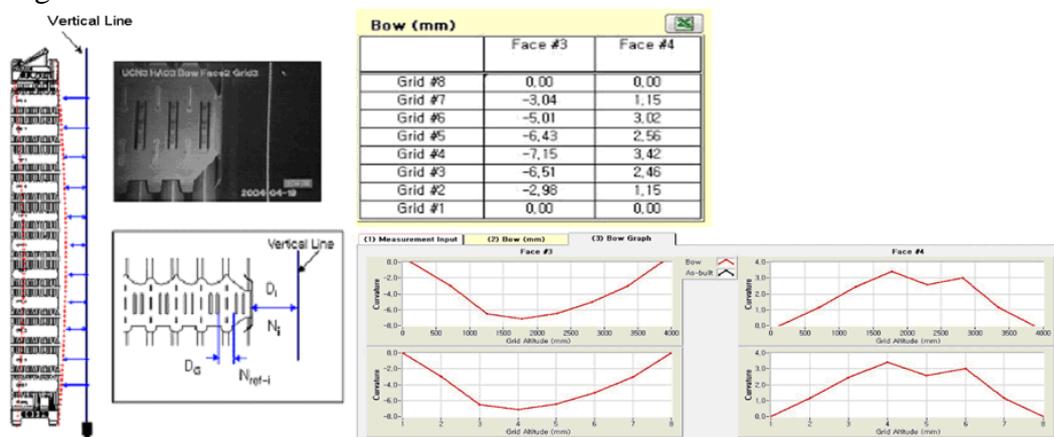|	Face #3	Face #4
Grid #8	0.00	0.00
Grid #7	-3.04	1.15
Grid #6	-5.01	3.02
Grid #5	-6.43	2.56
Grid #4	-7.15	3.42
Grid #3	-6.51	2.46
Grid #2	-2.98	1.15
Grid #1	0.00	0.00

Fig.5 Fuel Assembly Bow

2.2.1.3　Fuel Assembly Twist

The fuel assembly twist is defined as the relative twist degree of top and bottom nozzles, and it is used to evaluate the torsion of fuel assembly which caused by irradiation. The twist of fuel assembly may cause fuel assembly damage through interference between assemblies.

According to ruler calibration, the relationship between pixel value in the lateral direction and the angle of camera is obtained. Move the camera around to make the two vertical lines and top nozzle are in the image field of view, and make the two vertical lines coincide on the observation plane when the recording starts. The twist of fuel assembly is calculated by image processing software, and the measurement principle is shown in Fig.6.
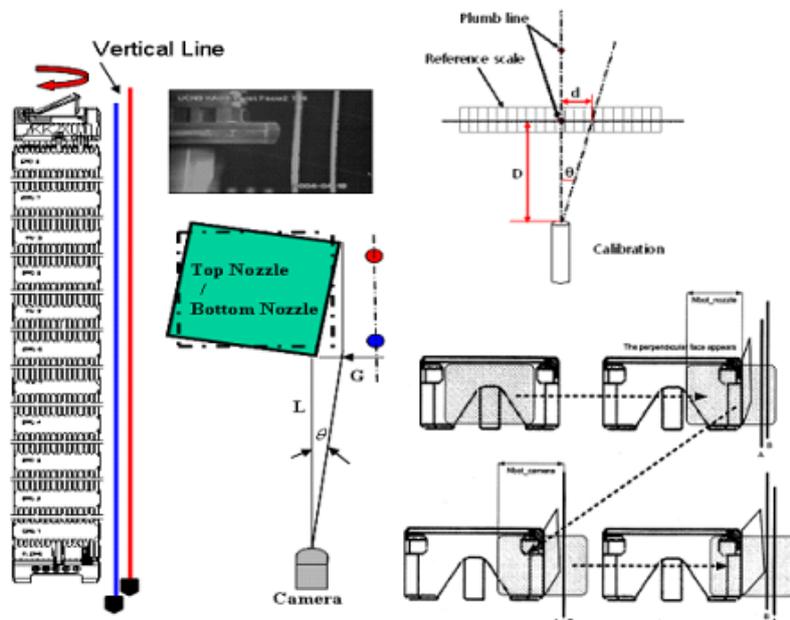

Fig.6 Fuel Assembly Twist

2.2.1.4　Shoulder Gap

The purpose of shoulder gap measurement is to evaluate the irradiation growth of fuel rods. The shoulder gap of outer fuel rods is measured. The should gap is defined as the distance from the bottom of top nozzle to the top of fuel rods and from the top of bottom nozzle to the end of fuel rods.

According to adjusting the position of the fuel assembly by crane, the image of top nozzle and fuel rods are in the observation area. The cameras are moved around and took video, the pixel values of shoulder gaps are achieved. The measured data and the
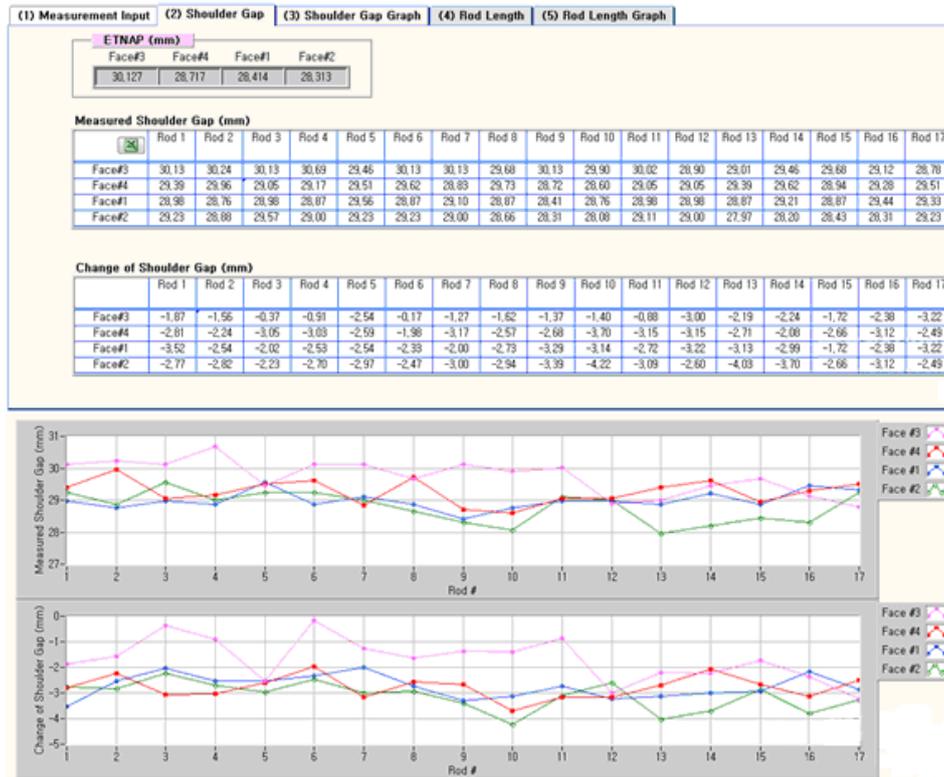
curve are shown in Fig.7.

Fig.7 Shoulder Gap Measurement

2.2.1.5 Rod Gaps

The purpose of rod gaps measurement is to evaluate the degree of bending deformation of irradiated fuel rods. The technology is to study the gaps of outer fuel rods, and the gaps between two adjacent fuel rods on grids span along the axial are achieved.

According to adjusting the position of the fuel assembly by crane, the image of fuel rods between two grids is observed. The pixel values of rod gaps are achieved by image processing software, and the measured data and curve are shown in Fig.8.
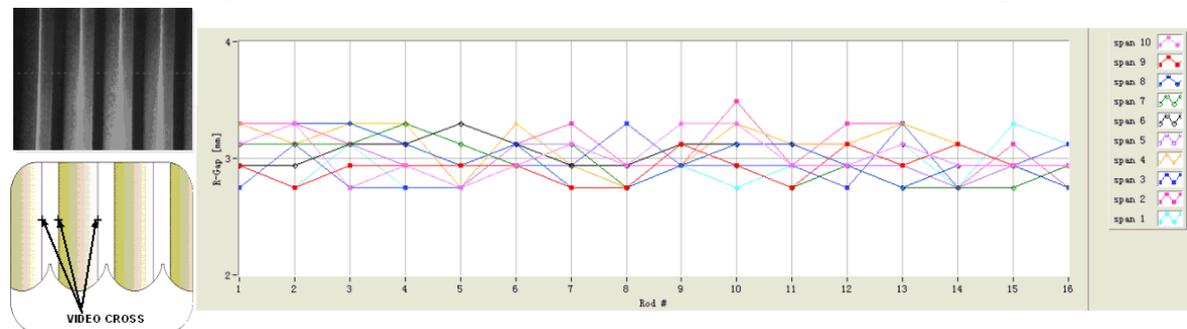

Fig.8 Rod Gap Measurement

2.2.2 LVDT Techniques

LVDT (Linear Variable Differential Transformer) measurement technique is to use the principle of electromagnetic induction to convert the measured displacement into mutual inductance changes of transformer coils. The change of measurement circuit is converted into voltage, and the variation is achieved from non-electricity to electricity[9].

2.2.2.1 Fuel Rod Diameter

Fuel rod diameter measurement technique is to study the diameter of outside fuel rods. The LVDT probe of diameter measurement is mounted on the working platform, standard rod is installed and the system is calibrated as shown in Fig.9.

Enter the measurement interface and set the parameters of fuel assembly. The surface of fuel rod is contacted by LVDT probe which measured rod from top to bottom. The average diameter in measurement area of fuel rod is achieved.
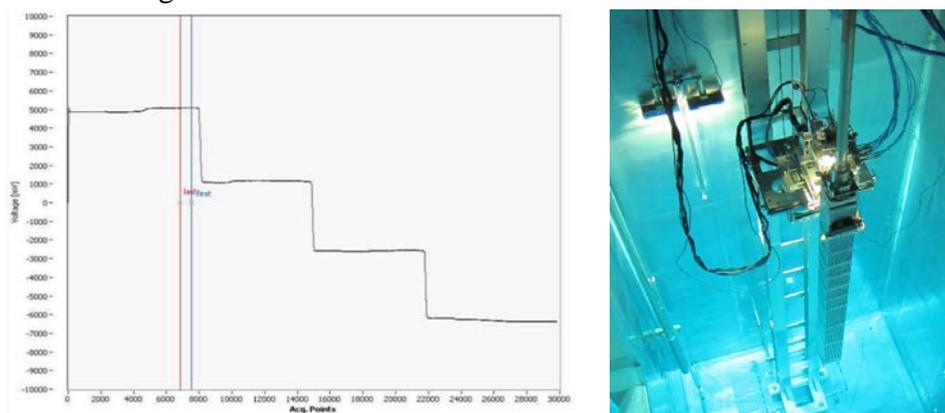

Fig.9 Standard Rod Diameter Calibration and measurement

2.2.2.2 Grid Width

The grid width measurement technique is to study measuring the width of fuel assembly grids.LVDT probe and positioning device are mounted on work platform, the LVDT is calibrated by standard grid width and the calibration datas are saved as shown in Fig.10. The fuel assembly grid width is measured as shown in Fig.11.
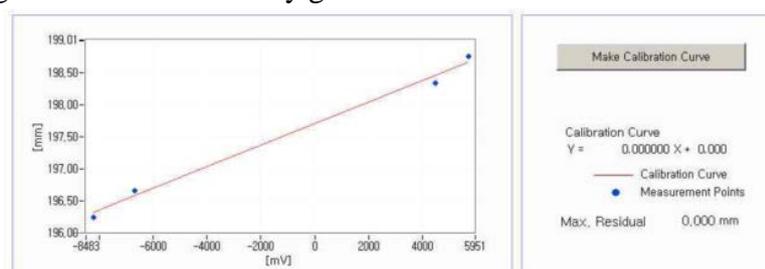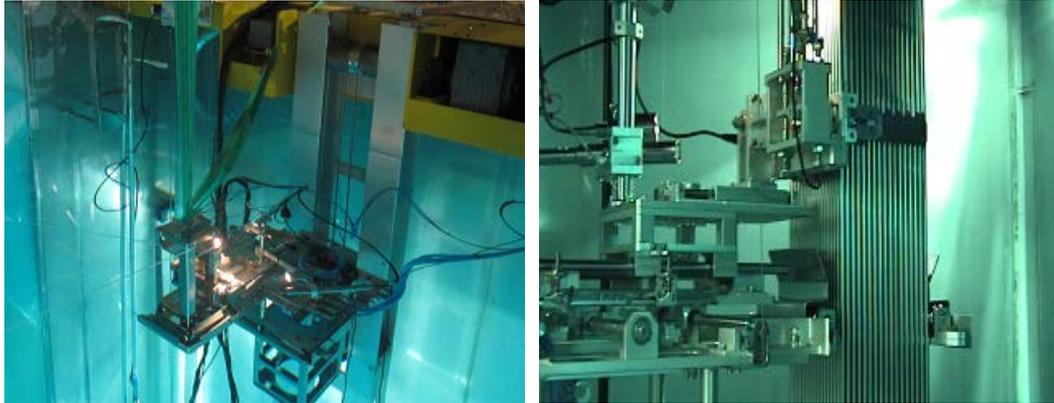

Fig.10 Standard Grid Width Calibration

a) Standard Grid Underwater Calibration   b) Grid Width Measurement

Fig.11 Grid Width Measurement

2.3 Eddy Oxide Thickness Measurement Technique

Water-side corrosion of cladding, especially oxide thickness increase is an important factor for limiting the life of fuel assembly. Eddy oxide thickness measurement technique is to use pen-type eddy current probe and lift-off effect principle of eddy current coil to measure oxide thickness of cladding.

The parameter of eddy current thickness is setting and calibration as shown in Fig.12a). The standard rod is calibrated by standard thickness film as shown in Fig.12b). The oxide thickness of fuel rods between two grids are measured and the measurement datas are saved as shown in Fig.13. The oxide thickness of standard rod is measured and the average of measurement datas is verificated.
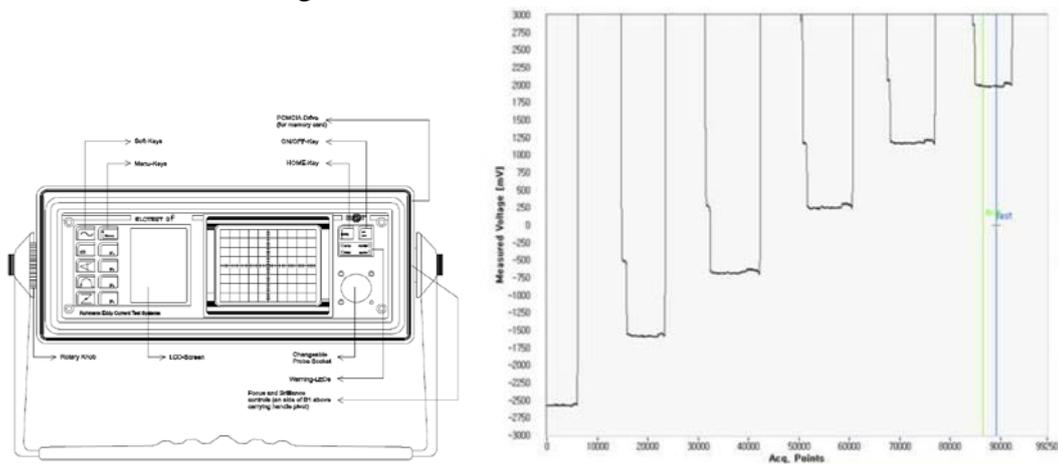
a) Eddy Current Thickness   b) Calibration Curve of Standard Film
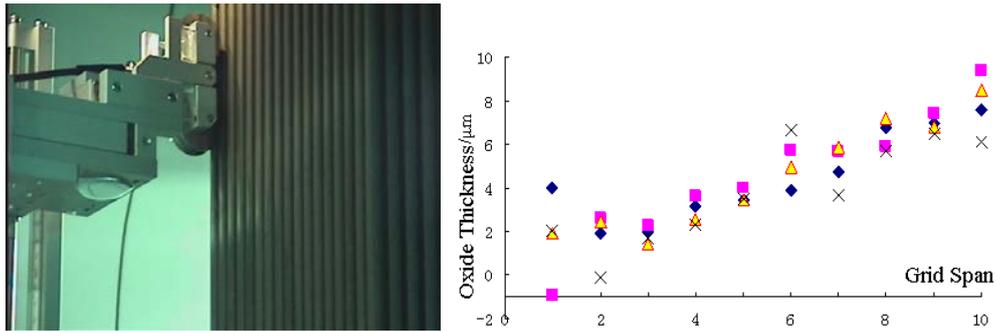
Fig.12 Oxide Thickness Equipment and Calibration

Fig.13 Oxide Thickness Measurement

3 Conclusions

1) The whole PSI system has been successfully used for inspection and

measurement in China;

2) It is an important significance for promoting China's advanced fuel assembly

design and safe operation of nuclear power plants by PSI technology.

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