Development of an underwater AUT system for reactor walls

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1. Introduction

KAERI(Korea Atomic Energy Research Institute) developed the KSNP(Korea Standard Nuclear Power Plant) in 1984. It was designed to generate 100MKw of electric power. The first KSNP was Ulchin Unit 3 constructed by Kepco(Korea Electric Power Corporation) in 1998. Korea has 6 KSNPs now.

These NPPs have pressurized water reactors. It must stand a 150~160 air pressure and 300 degrees centigrade heat. If there are some defects in the reactor, these conditions may cause serious accidents such as a loss of national electric power and human lives.

The reactor is made of carbon steel. It consists of a head, a body and a bottom head. There are welding areas on the body and bottom head. These welding areas are the weak points of the pressurized water reactor.

The regular maintenance procedures for the nuclear power plant safety instruments are executed during the overhaul period every fourteen months in a KSNP. The duration of an overhaul is 3 weeks. The reactor inspection is executed based on an international standard code such as the ASME(American Society of Mechanical Engineers) code. The UT inspection method is adapted for a reactor welding area inspection. It must be executed in radioactive water because contaminated water can not be moved to on other place. It takes a long time to execute this inspection by the traditional equipment. We developed an automated and compact system to inspect the KSNP reactor welding areas.

2. Inspection Method for a Korean Standard Reactor

The height and weight of the Korean Standard Reactor are about 11m and 300t each other. There are 4 welding areas[C1~C4] in the reactor body and bottom head. It has 6 welded nozzles, 4 for inlets and 2 for outlets.

The reactor inspection is executed on the C1~C4 and 6 nozzles. Figure 1 describes the inspection areas and inspection schemes for the underwater robot and table 1 explains the welding areas[1].

Table I: Welding area

C1	Between Flange and Upper Shell
C2	Between Upper Shell and Middle Shell
C3	Between Middle Shell and Lower Shell
C4	Between Lower Shell and Bottom Head
Nozzle	Between Nozzle and Middle Shell
	Between Nozzle and Nozzle Pipe

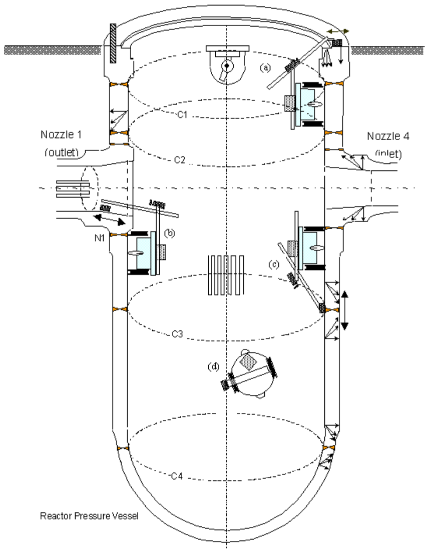

Figure 1. Inspection of a Korean Standard Reactor

There are two kinds of inspections methods. One is circumferential inspection and the other is nozzle inspection[1].

Table II. Inspection items of Korea standard Reactor

Symbol	Scanning Direction		UT probe / Probe Angle	Robot Po
Circumferencial Shell weld				
C1	DN	Flange	10.5°, 4.0°, -2.5°	(a)
	UP		0°,45°,60°, Slic	(c)
	CW		0°,45°,60°, Slic	(c)
	CCW		0°,45°,60°, Slic	(c)
C2				(c)
C3				(c)
C4				(d)
Nozzle(inlet : 0°,60°,180°, 240°)				
NI	Inside	Bore	5°, 45°	(b)
	Outside	Shell	0°,45°,60°, Slic	(b)
	CW	Shell	0°,45°,60°, Slic	(b)
	CCW	Shell	0°,45°,60°, Slic	(b)
NI-IRS	CW		Slic	(b)
	CCW		Slic	(b)
Nozzle(outlet : 120°, 300°)				
NO	Inside	Bore	0°, 45°	(b)
	Outside	Shell	0°,45°,60°, Slic	(b)
	CW	Shell	0°,45°,60°, Slic	(b)

	CCW	Shell	0°,45°,60°, Slic	(b)
NO-IRS	CW		Slic	(b)
	CCW		Slic	(b)

3. Design of the Inspection System

3.1 Specification

The inspection system specifications[2]:

① Inspection robot : It is an underwater mobile robot. It has four magnetic wheels. It moves along the reactor wall using these wheels. It has a 6-axis manipulator for an UT scanning and a PSD(Position Sensitive Detector) for a position recognition. Computerized processors are built in to it.

② Laser positioner : It is a pan-tilt device with 0.01 degree's resolution. It has a laser diode module and guides the inspection robot using it. The PSD on the robot sensing the position of the laser. A small PC-104 type computer is built in it.

③ UT analysis system : It is a data acquisition and analysis system. It is a real-time system based on lynx OS. It has a 5Mbyte/sec UT data acquisition capability.

④ Main control system : It controls the inspection robot, laser positioner and UT analysis system based on a network. It generates the robot's moving path and generates a set of commands for the whole inspection procedures.

Built-in robot controller in the robot controls its posture according to the position of the laser in the PSD and manipulator's movement according to the MCS's command. Whenever the UT probe passes a predefined inspection position (about every 2mm distance), it sends a trigger pulse for one UT pulse to the UT analysis system. [1]

3.2 System Descriptions

We needed 6-axis manipulators and a LVDT(Linear Variable Differential Transmitter) to inspect the reactor vessel wall. The posture of the robot manipulator during an UT inspection is illustrated in figure 2.

When the robot stretches the manipulator, the height of the LVDT is controlled and then the length of the pressurize spring attached between the UT probe and its holder is controlled and finally the pressure between the UT probe and reactor vessel wall. Displacement of the LVDT is feedback input and angle of the manipulator is control output.

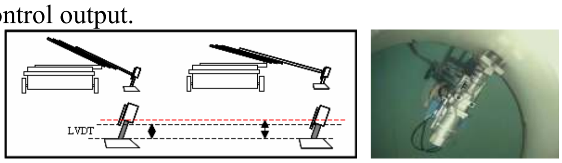

Figure 2. Control the UT probe pressure using LVDT

The functions of the robot controller are;
- Communicate with the Main control system.
- 7 Motors control (1 PSD and 6-axis manipulator) and a laser position detection.
- LVDT control and send trigger signals to the UT analysis system.

The functions of the main control system(MCS) are;
- Communicate with the laser positioner, the UT analysis system and the Robot. And control them.
- Generate a set of inspection commands and process them automatically based on an inspection error self-recovery algorithm.
- Show the inspection situation in 2-D graphics.

4. Experimental Overview of the Inspection System

Weight of the inspection robot is 45kg. Total weight of the inspection system is 130kg. When we execute an inspection in a KSNP, it only takes 2 hours for the system's installation.

The reactor UT inspection system that we developed is shown in the left side of Figure 3. The right side shows an experimental overview of the Ulchin unit 6 inspection at Doosan Heavy Industries.

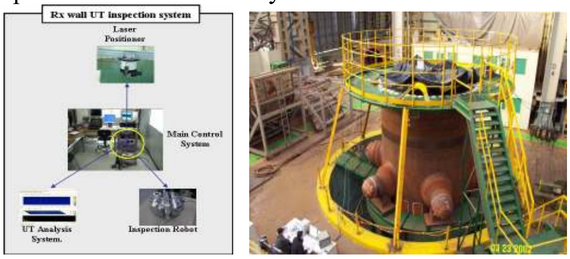

Figure 3. Experimental overview

Figure 4 shows the laser positioner on the Ulchin unit 6 reactor and one of the UT analysis graphic results for it. The UT analysis system generates an A·B·C-scan display. The results of the inspection for the Ulchin unit 6 were verified by KAITEC(major one of NDE service corporations in Korea.).

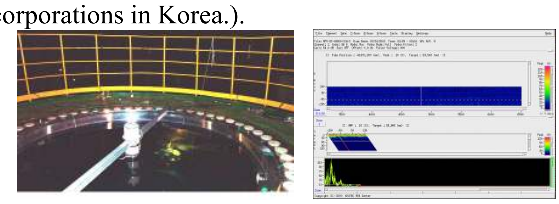

Figure 4. Laser positioner and UT analysis graphic interface

REFERENCES

[1] J. H. Kim, J. C. Lee, Y. R. Choi, Development of an automatic reactor inspection system, KAERI/RR-2239/01, 2002.

[2] J. H. Kim, J. C. Lee, Y. R. Choi, Development of a remote inspection system for NSSS components, KAERI/TR-2711/2004, 2004.