Development of Advanced Underwater Robot and Inspection System for Nuclear Reactor

Kim Younkyu [a], Kim Joonhong [a], Kim Jungbin [a], Dongil Kim [a], Park Minsu [a*]
[a]*Technology Research & Development Institute ,Kepco KPS, 211, Munhwa-ro, Naju-si, Jeollanam-do, 58217*
[*]*Corresponding author: mspark@kps.co.kr*

1. Introduction

To ensure integrity of the nuclear power plant, the main welds on the reactor vessel are remotely inspected by Non-destructive testing in accordance with the KEPIC MI or ASME code section XI. However, It is difficult to perform the automatic testing in high radiation areas of underwater[1]. KEPCO KPS has been conducting the Conventional Ultrasonic Testing(UT) with inspection robot, ROSA V, from the Westinghouse since the late 1990s. Recently, the reactor inspection method has been changed from the conventional UT to the Phase Array UT(PAUT) for better flaw detectability. PAUT is increasingly adopted for automatic inspection of nuclear components, since it can improve probability of detections and sensitivity.

In this study, advanced underwater robot and PAUT system for reactor vessel are introduced and described for the field application.

2. Development Status

2.1 System layout

The AURoRA[1], the reactor vessel underwater robot developed to replace ROSA V system in use, is an 7-axis robot developed by KEPCO KPS, and can be added 2-axis at the end, thus having 9 axes of freedom. It is designed to have a waterproof structure to work at 50M underwater, and the link length for each axis was expanded by the reactor type (APR1400, OPR1000, W/H, Framatome). Each axis is made of an integral module of the motor, reducer, brake and resolver. It is easy to maintain in the field in case of trouble, and related parts are designed as commercial standard parts, making it easy to supply parts.

Table I: AURoRA Specification

	Specification
Weight	250kg(50M cable included)
Payload	35Kg(in Air)
D.O.F	7axes+2 axes
Repeatability	±1mm
Arm Length	2820mm(Link exchange)
Others	50M water proof Radiation tolerant

[1] AURoRA : Advanced Underwater Robot for Reactor Assessment

The control system was manufactured using a commercial robot controller and Realtime encoder method was applied by improving pulse generation method of existing system for accurate transfer of inspection position of non-destructive inspection system.

The End effectors and Sleds (Shell, Pipe, Nozzle, SI) have been developed for mounting PA probes. The sleds for Shell and Pipe are installed in the "+" format, and the Nozzle sled is installed horizontally with two probes. The sled for SI is developed in a cylindrical form on the end effector in a separate 2-axis scanner. Robot operation system is a 3D OLP (Off-line Programming) -based robot control / operation software in the windows environment. It implements a 3D virtual workspace for the reactor so operator can easily create the inspection path and analyze the problems related to the collision or operation. This operation program is designed to facilitate inspection activities by integrating 3D modeling and inspection paths of all nuclear reactors in Korea.

Fig. 1.The AURoRA robot installed in APR1400 Mockup.

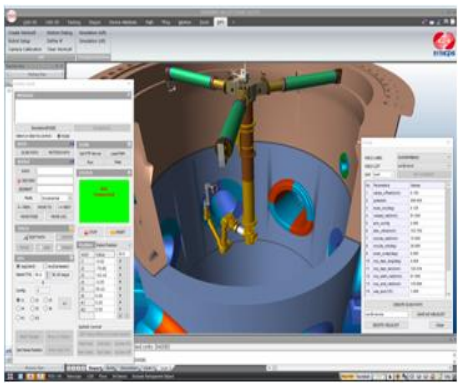

Fig.2. The AURoRA operating S/W featured 3D GUI

The SPAcE[2] (PAUT equipment and software) was developed to optimize the reactor vessel inspection. After inputting the work environment and inspection data, it communicates with the developed robot system to receive the location of the probe and the ultrasonic signal data collected automatically. The PA probe types are Shell probe, PIPE probe, Nozzle probe and SI probe. The Shell, PIPE, Nozzle probes are consisted of 26 elements and SI probe is 18 elements. These Probes are designed through simulations and various tests.

Fig.3. SPAcE PAUT System with 4 channels

2.2 Verification

To ensure reliability in the field, The SPAcE, PA probes, and Inspection Procedure were certified PD (Performance Demonstration) from EPRI in the United States. Performance Demonstration is a verification system that detects and evaluates flaws using UT techniques and inspection equipment for flaws similar to actual flaws generated in welding parts of major facilities of nuclear power plants[3]. There is no PD for reactor vessel in Korea, so the certification is required by U. S. EPRI. KEPCO KPS was certified EPRI PD the first in Korea, and the third in the world under the automatic PAUT inspection for reactor vessel.

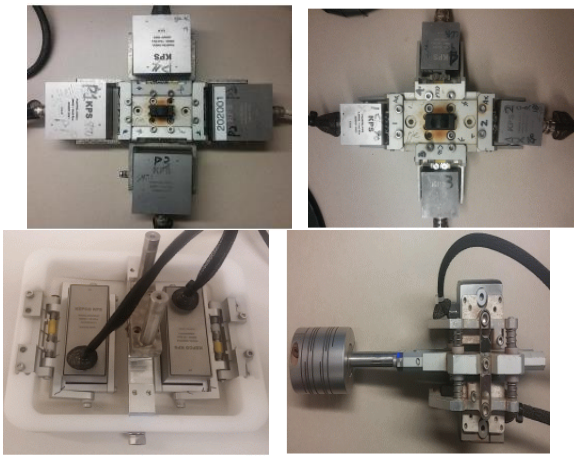

Fig.4. Sleds for PA Probe (Shell, Pipe, Nozzle, SI)

2.3 Field Application

From February 19, 2018, we carried out a field Application on the reactor vessel of Shinhanul Unit 2 Pre Service Inspection. The equipment used in the field was collected by using the AURoRA robot system and the SPAcE inspection system for the reactor vessel G-2(Shell), N-2(Outlet Nozzle) and N-2 pipe(Nozzle to Pipe). As a Result, indication exceeding the tolerance criteria was not found

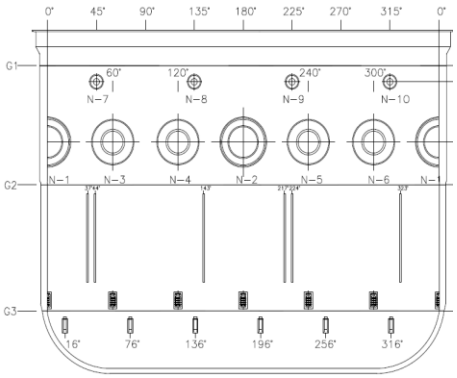

Fig.5. ShinhanulUnit2 Vessel Rollout

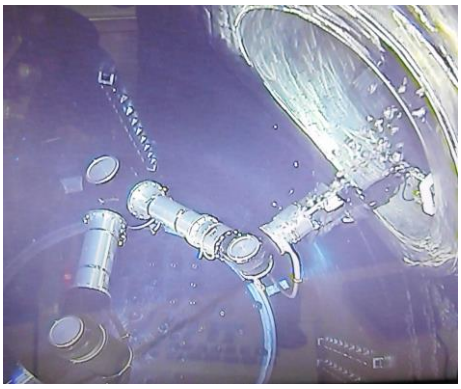

Fig.6. The AURoRA Scanning the Nozzle to Pipe under the water on Shinhanul unit2

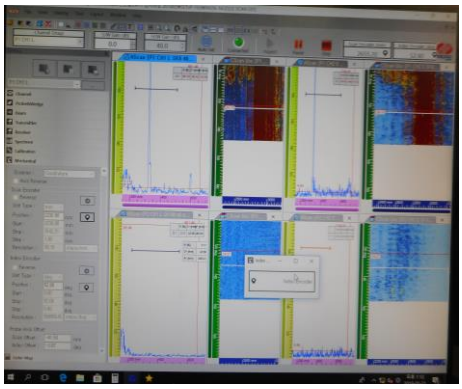

Fig.7. Acquisition PAUT data using The SPAcE

3. Conclusions

[2] SPAcE: Smart Phased array Acquisition and Evaluation system

the robot system “AURoRA” and the inspection system “SPAcE”, which were developed KEPCO KPS, were compared with the commercial PAUT data collected for the same inspection site as a result of the field test. It was verified that the position control, inspection area scan, and signal acquisition can be stably checked in the underwater environment. We are currently improving the problems from the field test. After 2020, we plan to replace the existing Westinghouse ROSA V robot system and PARAGON (Conventional UT) inspection system. In addition, development is underway to expand the application to the automatic non-destructive inspection of nuclear Components

REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section XI(1995)
[2] Park M.S. et al." Development of a next generation system for automated non-destructive testing of export nuclear reactors and development of technology for international certification", Technical report(KETEP, 2016)
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