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Development of a Remotely-operated Visual Inspection System for Reactor Vessel Bottom-mounted Instrument Penetrations of KSNP and Lessons Learned

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1. Introduction

In April 2003, South Texas Project Unit 1 made a surprising discovery of boron acid leakage from two nozzles from a bare-metal examination of the reactor vessel bottom-mounted instrument penetrations during a routine refueling outage. A small powdery substance about 150mg was found on the outside of two instrument guide penetration nozzles on the bottom of the reactor. The primary coolant water of pressurized water reactors has caused cracking in penetrations with Alloy 600 through a process called primary water stress corrosion cracking.

In South Korea, it is required to conduct 100% visual inspection of the outside of instrument guide penetration nozzles on the bottom of PWRs to confirm the integrity of reactor vessel.

This paper describes the remotely-operated visual inspection systems for reactor vessel bottom-mounted instrument penetrations dispatched two times to Youngkwang NPPs and discusses the lessons learned.

2. Working Environments

As shown in Figure 1, the bottom head area of the reactors of KSNPs have insulation designs that make effective bare-metal examinations impractical without removing some or all of the insulation. It is because that though the design enables to remove several insulation panels, human workers could suffer from radiation during the inspection. Thus there arose the need for remotely operated robotic inspection systems.

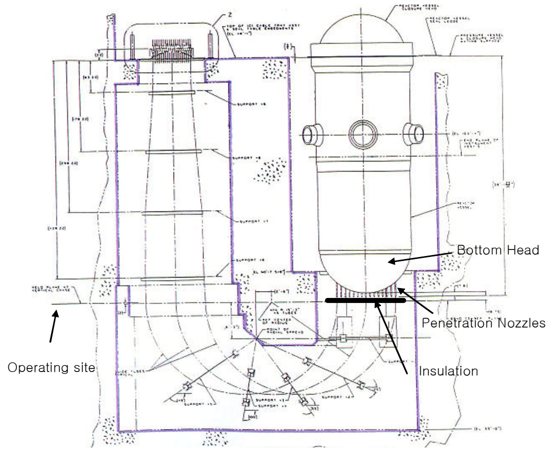

Figure 1. Structures under the reactor of KSNP.

To protect human operators from the radiation, operating site should reside far away from the reactor about 50 meters.

As shown in Figure 2, inside the bottom head of KSNP, 45 penetration nozzles with the radius of about 7.5cm are mounted. The height of the nozzle located on the center is about 6 and the minimum distance between the nozzles is about 20 cm.

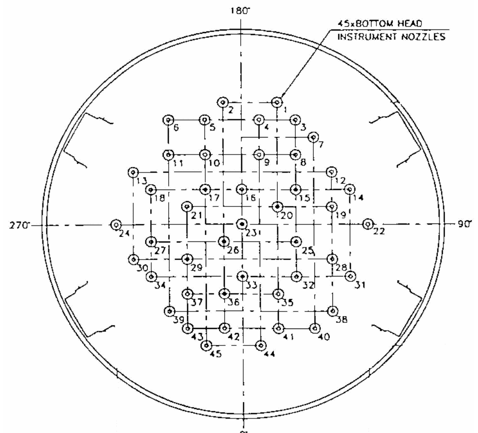

Figure 2. View of the bottom head of reactor of KSNP.

3. Development of Visual Inspection System

Two systems were developed and deployed in Oct, 2004 and in Aug, 2005.

The structure of the system developed first is depicted in Figure 3. One mobile robot (named ATOM-M) has a high performance zoom camera to acquire the detailed images of the nozzle and has relatively large mobile platform, and can not enter into the center area of the bottom. The other mobile robot (named ATOM-S) has a miniature CCD camera with fixed focal length, and its size is small to approach the central area. Two robots can monitor each other using its own camera to enhance the efficiency of remote operation.

The portable remote control system consists of a PC-based controller and a VTR and 3 LCD display. The system is mainly operated with a game joystick and a PC keyboard is used to type-in overlay texts.

The system was deployed to the Reactor #4 of Youngkwang NPP in OCT, 2004 and carried out the desired inspection missions successfully as a whole.

However, there were some problems to be solved in order to accomplish the inspection task in the next year.

The cable winding mechanisms were too heavy to move and human workers got relatively large radiations doing the job. The laser slit beams were no use to enhance the human perception of the interior 3-D structures below the bottom of the reactor. And the quad-images from the 4 auxiliary cameras mounted on ATOM-M are too small to help understanding the environment around the robot. We concluded that they had rather increased the system complexity.

The human inspectors participated in the inspection tasks also requested that the orientation of the inspection camera should be displayed to easily identify the nozzle from the images.

Thus we decided to develop a new inspection robotic system having only one mobile robot with low height to reduce the number of the cable winding mechanism to only one. We left only one auxiliary camera to simplify the system. One observation camera was included to the cable winding mechanism in order to view the mobile robot.

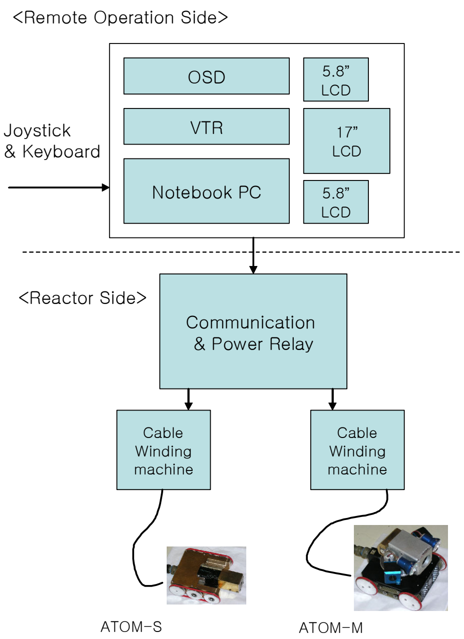

Figure 3. Structure of the visual inspection system developed

Figure 4 shows the new mobile robot whose left and right wheels are driven separately with 2 DC motors. In addition to the camera panning and tilting mechanisms, camera lifting mechanism was implemented to lower the height of the robot when the robot inspects the central areas. To reduce the size of the camera module, we adopted 6 power LEDs instead of halogen lamps.

The weight of the cable winding mechanism was also reduced to about 8kgs to be handled easily.

Though the desktop joystick was used to command the robot in the first development, a hand-held SONY PS-2 joystick was adopted in the second development which was proved to control the robot easier. The notebook computer was replaced with a small microcontroller board. So the size of the remote control box was decreased accordingly. The new system was used for the reactor #4 of Youngkwang NPPs in SEP 2005, and it remarkably reduced the inspection time.

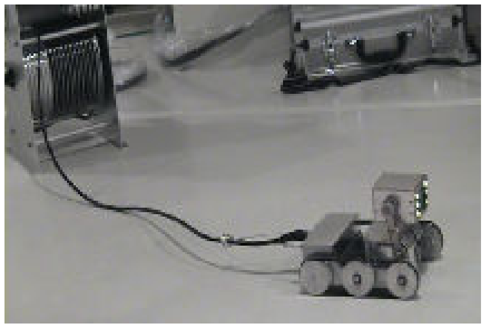

Figure 4. Cable winding mechanism and ATOM-M1

Figure 5. Control interface using a SONY hand-held joystick

4. Conclusion

KAERI developed a couple of mobile robotic systems for emergency response in NPPs. They were integrated with high level technologies, but could not be used in real fields because they were too expensive and the needs for them were not urgent. However the ROV and the visual inspection system for the reactor bottom mounted nozzles could be used in real fields because they are not so expensive and affordable by adopting inexpensive commercial components. With the experiences obtained from their use, they could have the opportunities for improvement and could satisfy the needs requesting from the fields without applying high level technologies.

REFERENCES

[1] B. Sheron, "On reactor vessel degradation," Nuclear News, June 2003, pp. 29-33, 2003.

[2] T. Smith, M. Wiese, "All eyes on Texas," POWER, NOV/DEC 2003.

[3] E. Conaway, "South Texas Project Employs High-Tech Solution to Residue Issue," Nuclear Energy Insight, Oct, 2003.

[4] S.W. Glass, R.F. Cole, "Inspection and Repair Technology for BMI Penetrations," Proc. Of ICONE12, pp.1-6,2004.