A Visual Inspection System Development for the Reactor Vessel Bottom-mounted Instrument Penetrations

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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 scheduled to conduct visual inspection of the outside of instrument guide penetration nozzles on the bottom of PWRs to confirm the integrity of reactor vessel.

As shown in figure 1, 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.

In order to inspect the possible leakage of boron acid, two mobile robots are developed and described in this paper.

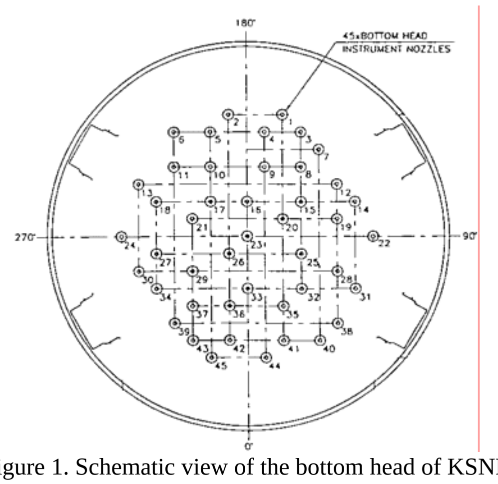

Figure 1. Schematic view of the bottom head of KSNP

2. Methods and Results

Resulting from the analysis of the working environment using the design schematics, visual inspection system consisting of two types of mobile robot are suggested because it is assumed to be hard to develop a very small mobile robot performing such inspection properly inside the small confined working area during the required developing time.

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 it's size is small to approach the central area. Two robot can monitor each other using its own camera to enhance the efficiency of remote operation.

2.1 Structure of the Developed System

The structure of the developed system is depicted in Fig. 1. 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 caption texts overlayed on captured camera images.

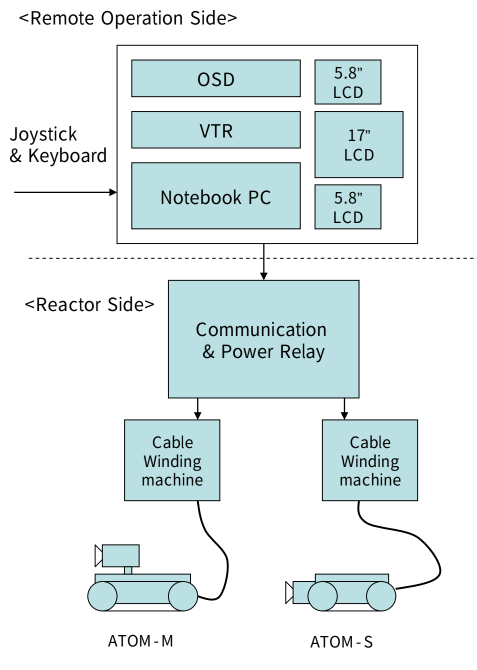

Figure 2. Structure of the visual inspection system developed

The remote controller and two robots are linked through RS485 communication and the tether cable contains total 8 cores consisting of two coaxial cables for video transmissions and one twisted pair for RS485 communication and one pair of power lines.

In figure 3, the main 17” LCD displays the inspection image and the left 5.8” LCD monitor shows the quad-images obtained from ATOM-M.

Figure 3. Operation of Remote Controller

2.2 ATOM-M

The wheels of ATOM-M are actuated with two DC motors and the front and rear wheels are synchronized by timing belt in each side. A pan and tilt mechanism orients the camera head to any direction.

The Inspection camera of the ATOM-M is a SONY CCD camera with 10X optical zoom. To enhance the perception capability of operator inside such unfamiliar environment, four additional cameras with fixed focal length are mounted on the mobile platform. Two cameras are attached on the left and right sides of the inspection camera module, and other two cameras are fixed to the front and rear sides of the mobile platform.

An 8051-based controller is embedded inside the frame to control the four DC motors and the zoom and focus functions of the camera.

To reduce the radius of the tether cable, a four-channel video controller is embedded inside the mobile platform and generates a quad-video image from the four video signals.

Laser slit beams can be generated to recognize 3 dimensional shapes. Two 20W halogen lamps and array of bright LEDs are mounted. The dimension of ATOM-M is 160mm(H) x 160mm(W) x 190mm(L).

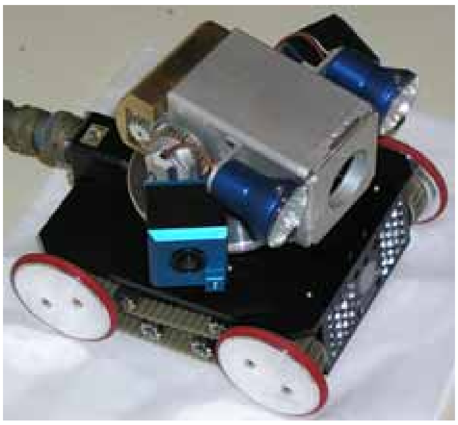

Figure 4. ATOM-M

2.3 ATOM-S

ATOM-S drives 6 wheels by two small DC motor modules and three wheels in each side are connected with silicon rubber belt. The DC motor module is commercial and contains gear box and motor controller. And it is small to fit into the desired size of the mobile platform and allows easy velocity/position controls via RS232C commands from remote host controller.

The small inspection camera module has a fixed focal length CCD camera and a tilt and pan mechanism. A circular array of bright LEDs are mounted on the front of the camera head. The dimension of ATOM-S is 50mm(H) x 155mm(W) x 210mm(L).

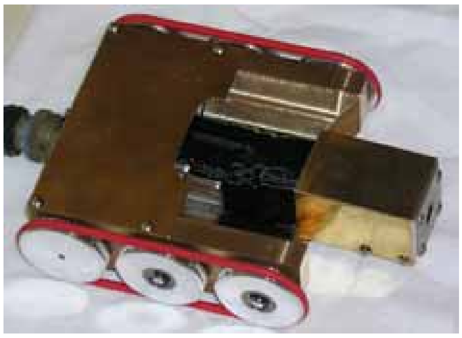

Figure 5. ATOM-S

3. Conclusion

The developed system was tested inside a simplified bottom head mockups and deployed into a real reactor to conduct visual inspection. The system was performed well enough to finish the required inspection successfully until the scheduled time, but was requested for minor modifications to improve the efficiency.

We redesigned a new robotic platform to enhance the performance and to eliminate some rarely used functions for system simplification based on the experiences obtained from the first deployment.

ACKNOWLEDGMENTS

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