The Robots for Nuclear Power Plants

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1. Introduction

Nuclear energy becomes a major energy source worldwide even though the debating environmental and safety dispute. In order to cope with the issues related to the nuclear power plant, the uncertain human factors need to be minimized by automating the inspection and maintenance work done by human workers. The demands of robotic system in nuclear industry have been growing to ensure the safety of nuclear facilities, to detect early unusual condition of it through an inspection, to protect the human workers from irradiation, and to maintain it efficiently.

NRL (Nuclear Robotics Laboratory) in KAERI has been developing robotic systems to inspect and maintain nuclear power plants in stead of human workers for over thirteen years. In order to carry out useful tasks, a nuclear robot generally requires the followings. First, the robot should be protected against radiation. Second, a mobile system is required to access to the work place. Third, a kind of manipulator is required to complete the tasks such as handling radioactive wastes and other contaminated objects, etc. Fourth, a sensing system such as cameras, ultrasonic sensors, temperature sensors, dosimetry equipments etc., are required for operators to observe the work place. Lastly, a control system to help the operators control the robots. The control system generally consists of a supervisory control part and remote control part. The supervisory control part consists of a man-machine interface such as 3D graphics and a joystick. The remote control part manages the robot so that it follow the operator's command.

2. Nuclear Robots

2.1. Mobile Platform

The KAEROT series are multi-functional mobile robotic systems for the inspection and maintenance of a primary system in a nuclear power plant. It consists of a mobile system, a manipulator or a mast mechanism and sensory systems. The mobile systems are designed to have the features of modularity and reliability as well as stability. The KAEROT in Fig. 1(a) is four planetary-wheeled mobile robot capable of ascending and descending stairs and navigating a flat surface with a zero turning radius. The KAEROT/m1 in Fig. 1(b) has planetary wheels with three small omni directional wheels that have six elliptical shaped rollers which make it moves in any directions. A manipulator is mounted on the top of the mobile system which has a 6 DOF. The electrical-driven manipulator is designed to handle a 5kg payload at the end-effector at a full length, with a resolution of 0.3mm on all the axes for fine positioning of the end-effector. The KAEROT/m2 in Fig. 1(c) and (d) is especially designed for inspecting the Calandria, a front side of the PHWR, when the reactor is on operation. It has a wheel-drive mechanism with four tracks to climb and pass through obstacles. The 10 meter-long mast mechanism enables to inspect the pressure tubes and feeder pipes precisely by an infrared camera.

2.2. Reactor Vessel Inspection Robot

The presence of loose parts in the primary coolant system can be an indication of degraded reactor safety resulting from failure or weakening of a safety-related component. A loose part, whether it is from a failed or weakened component or from an item inadvertently left in the primary coolant system during construction, refueling, or maintenance such as loose metallic parts,bolts, nuts and washers can contribute to component damage and material wear by frequent impacting with other parts in the system. A loose part increases the possibility for control rod jamming and for accumulation of increased levels of radioactive crud in the primary coolant system. NRL is developing the underwater mobile robot for loose part detection and removal in the nuclear reactor vessel. The robot was deployed to inspect the loss of the RTD (Reactor

Fig. 1 KAEROT series mobile robots.

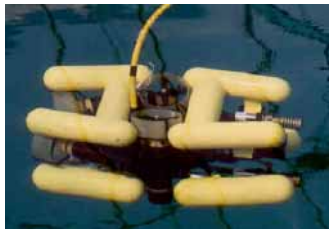

Fig. 2 Underwater robot for reactor vessel inspection.

This paper is supported by the Korea Atomic energy Research Institute as a project of "The Development of Radiation Hardened Robot for Nuclear Facility" sponsored by the Ministry of Science and Technology, Korea

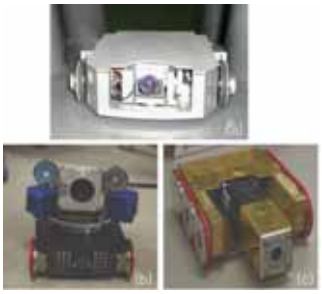

Fig. 1 Reactor head and bottom inspection robots.

Thermal Detector) sensor at Youngkwang unit 5 in 2004.

2.3 Reactor Exterior Inspection Robot

The PWR has Control Rod Drive (CRD) Nozzles at the reactor head and many instrumental nozzles at the bottom of the reactor. The former house the CRD Mechanism (CRDM) that regulates the power output of the reactor and the latter have the sensors to detect the neutron emission and temperature of the reactor.

The primary method for detecting leaks from the CRD head penetration nozzle is to perform a visual examination of the welding part in nozzle and head intersection. Any areas that exhibit characteristic called as ``white deposits" are indicative of boron salt residue coming from a primary coolant leak.

NRL was developed a robotic system to inspect the reactor head as shown in Fig. 3(a). The robot can move between CRDMs and attached to the reactor head surface by using a magnetic wheel to prevent from skidding. Fig. 3(b) shows the reactor bottom inspection robots, which has a high resolution pan/tilt camera and three additional cameras with different view angle. The slave robot shown in Fig. 3(c) observes the movement of the main robot and help the robot operator to control it easily.

2.4 Feeder Pipe Inspection Robot

The outlet feeder pipe thinning in a PHWR is caused by high pressure steam flow inside the pipe, which is a well known degradation mechanism called FAC (Flow Assisted Corrosion). In order to monitor the degradation, the thickness of the outlet bends closed to the exit of the pressure tube should be measured and analyzed at every official overhaul. NRL has been developing a mobile feeder pipe inspection robot that automatizes the measurement process. The robot can move by itself on the feeder pipe by using an inch worm mechanism, which is constructed by two gripper bodies that can fix the robot body on the pipe and one extension/contraction actuator and a rotation actuator connected the two gripper bodies to move forward and

Fig. 4 Feeder pipe inspection robot.

Fig. 5 Steam generator inspection and maintenance robotic systems.

backward and to rotate in the circumferential direction. Those actuators are drived pneumatically which are embedded inside the robot body to reduce the size of the robot so that it is applicable to the actual feeder pipes in the PHWR (Pressurized Heavy Water Reactor).

2.4 Steam Generator Inspection / Maintenance Robot

NRL developed a radiation hardened robotic system to assist automatic non-destructive testing and the repair of nuclear steam generator tubes without human workers in the plenum. Eddy-current testing and evaluation technique are used to validate the integrity of the tubes. The robotic system consist of a five DOF robot manipulator, multi-axis robot controller, sensor control and data acquisition system, and robot host controller. The robot manipulator has scalar type two DOF robot manipulator and three DOF trunk mechanism for adjusting the position and orientation of the manipulator. Industrial multi-axis motor controller and driver is used for the local controller, and windows based host control program is developed assisted by 3D graphics, which helps the robot operator.

4. Conclusions

Since the energy policy of the countries worldwide concerns mostly with the environmental issues which will be a major factor near future, the need for nuclear energy emerges more and more. Then, the robotic system that is closely related to the safety in both the power plant and the workers will take an important position in nuclear industry.

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