Long Reach Manipulator for PCV Repair at Fukushima Daiichi – 17082

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ABSTRACT

Various Research and Development (R&D) efforts related to the retrieval of damaged fuel debris at Fukushima Daiichi Nuclear Power Plant in Japan have been made since the accident occurred in March 2011. Since 2012, the Primary Containment Vessel (PCV) Repair Project has been one of the major improvement tasks required in the reactor buildings in order to start fuel debris retrieval activities. The primary purpose of this project is to create a water boundary in the lower sections of the PCV using remote handling methods.

A designated long reach remote manipulator for this project, called the Fukushima Repair Manipulator (FRM), has been developed to perform inspection, light demolition, and deployment of various tools to supply sealing material to fill the vent tubes as a part of the PCV Repair Project. The FRM is a single hydraulic manipulator which has 7 degrees of freedom, over 9m reach, tool change capability and a payload of 50kg at maximum reach. These features provide a safe, robust, efficient and allow for flexible operations in limited access and visibility around the operating area.

This paper will provide a system description of this manipulator and planned remote operations for the PCV Repair Project.

INTRODUCTION

The vent tube water sealing method is one of major water sealing methods to make water boundary at the lower part of PCV. This method is to seal the eight vent tubes connected to the drywell by using water seal material like a grout. Figure 1 shows a concept of the vent tube water sealing method [1]. Inflatable bags are placed in the end part of vent tubes at first, and then the inflatable bags are inflated by air and grout to make a temporary seal for water from upstream of the vent tubes. Finally, water seal material is filled in the upstream of the inflatable bags to completely stop water flow to downstream of the vent tubes.

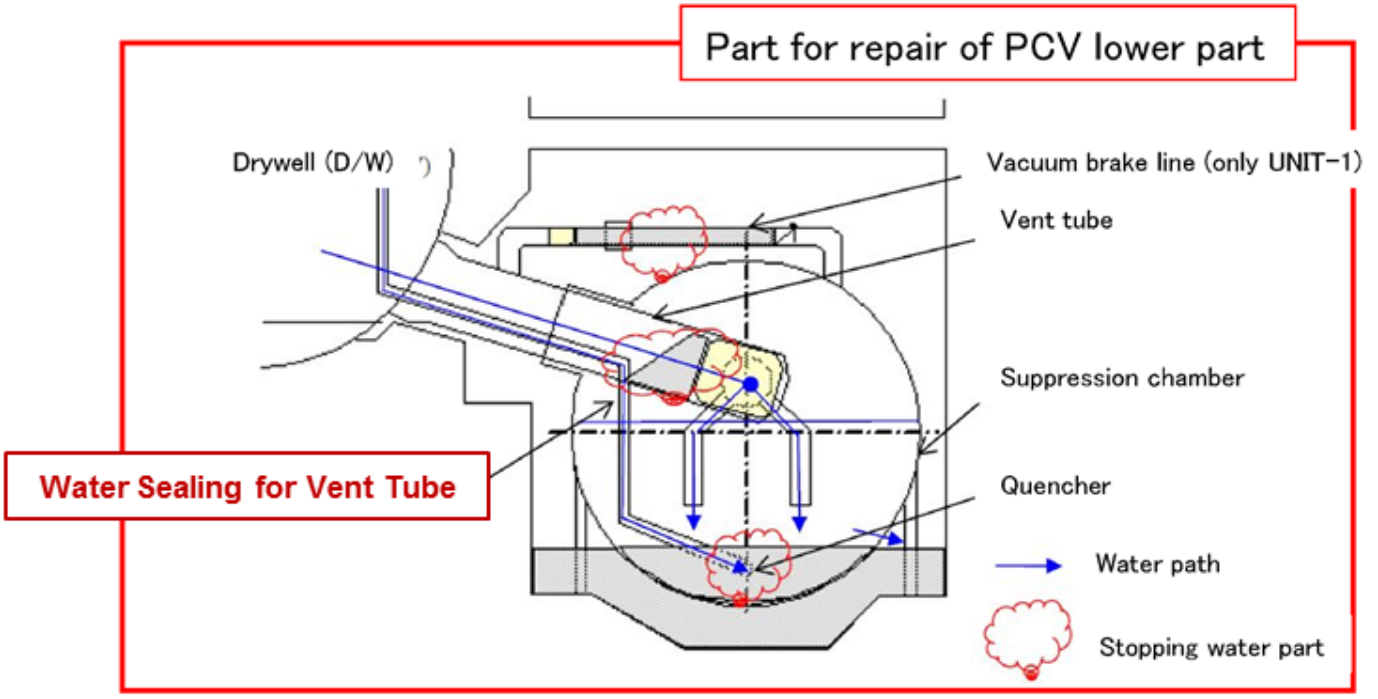

Figure 1: Concept of Vent Tube Water Seal Method [1]

Full remote operation is required to perform most of tasks for the vent tube water sealing as shown in Table 1. Those remote operations have high difficulties due to completely darkness, very limited space and complexities of components in the torus room and suppression chamber. Additionally, it is very short time for workers to be able to stay the installation area of the equipment located in the first floor of the reactor building due to high dose rate and highly-limited geometry. From these reasons shown above, it was necessary to develop the equipment which is applicable to limited installation space, limited manual operations, and provides high remote controllability.

Fukushima Repair Manipulator (FRM) was developed to perform those challenging remote operations practically. The FRM was designed to be long reach, provide high payload and operators-friendly control system, based on the Fukushima Inspection Manipulator (FIM) [2] which was developed for the project to inspect lower part of PCV. Development for the FRM was started in 2012. Design, manufacturing and functional testing for major components of the FRM were finished by March, 2016.

Table 1: Tasks to Create Water Boundary for Vent Tube

#	Tasks
1	Transportation, Installation and Deployment of the FRM and Support Equipment
2	Cut the Obstacles in the Torus Room
3	Access the Surface of the Suppression Chamber (SC)
4	Make a Hole in the SC
5	Cut the Obstacles in the SC
6	Access the Vent Tube
7	Locate the Hole Positions on the Vent Tube
8	Make the Holes in the Vent Tube
9	Cut the Obstacles in the Vent Tube
10	Install the Inflatable Bag in the Vent Tube
11	Monitor the Bag Inflation and Grouting Operation
12	Disconnect and Retract the Hose to the Inflatable Bag
13	Install the Water Seal Material Hose in the Second Vent Tube Hole
14	Monitor Water Seal Material Supply and Water Leakage
15	Retract the Water Seal Material Hose
16	Uninstall the Equipment and Move to the Next Position and Repeat Process Until Complete for Eight Locations of the Vent Tubes

DESCRIPTION

Fukushima Repair Manipulator

FRM is a single hydraulic manipulator arm with a very compact collapsed configuration. The arm has 7 degrees of freedom and over 9m reach. It provides 50kg in any directions of the arm movement. Carbon-fiber used for main material of telescopic tubes of the arm allows for the arm to be long reach but have relatively high payload. This is one of main features of the FRM. The FRM components and degree of freedom are shown in Figure 2. The arm is composed of

a main mast, elbow, forearm and wrist section. Diameter of the arm is about 300mm and total maximum length of the main mast and the forearm is about 9.4m as shown in Figure 3. The elbow connected between the mast and the forearm has two joints. It allows the forearm to flex over 190 degree, allowing the forearm to fold back against the vertical main mast for stowing and to provide the arm to have a wide range of motion. The wrist at the end of the forearm has 360 degree of rotation and 180 degree of pitch actuators. These two actuators provide flexible and precise remote operations in narrow area of the suppression chamber.

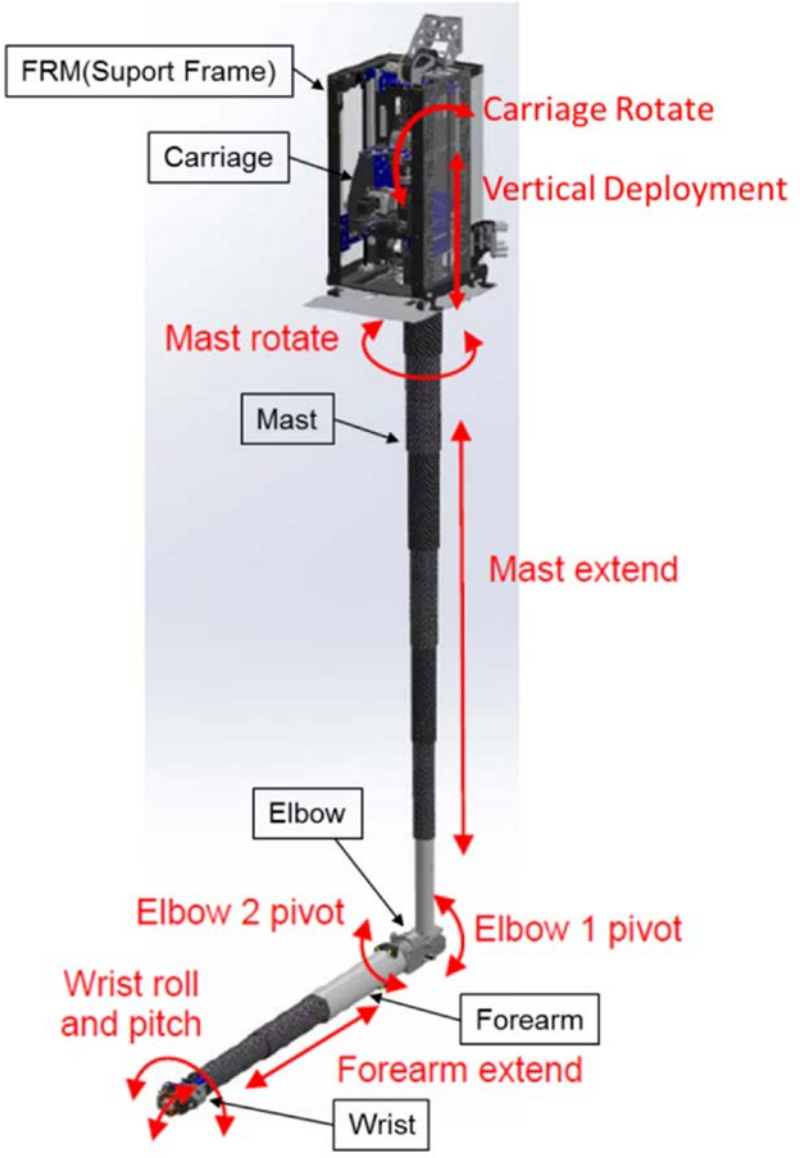

Figure 2: FRM Components and Degree of Freedom.

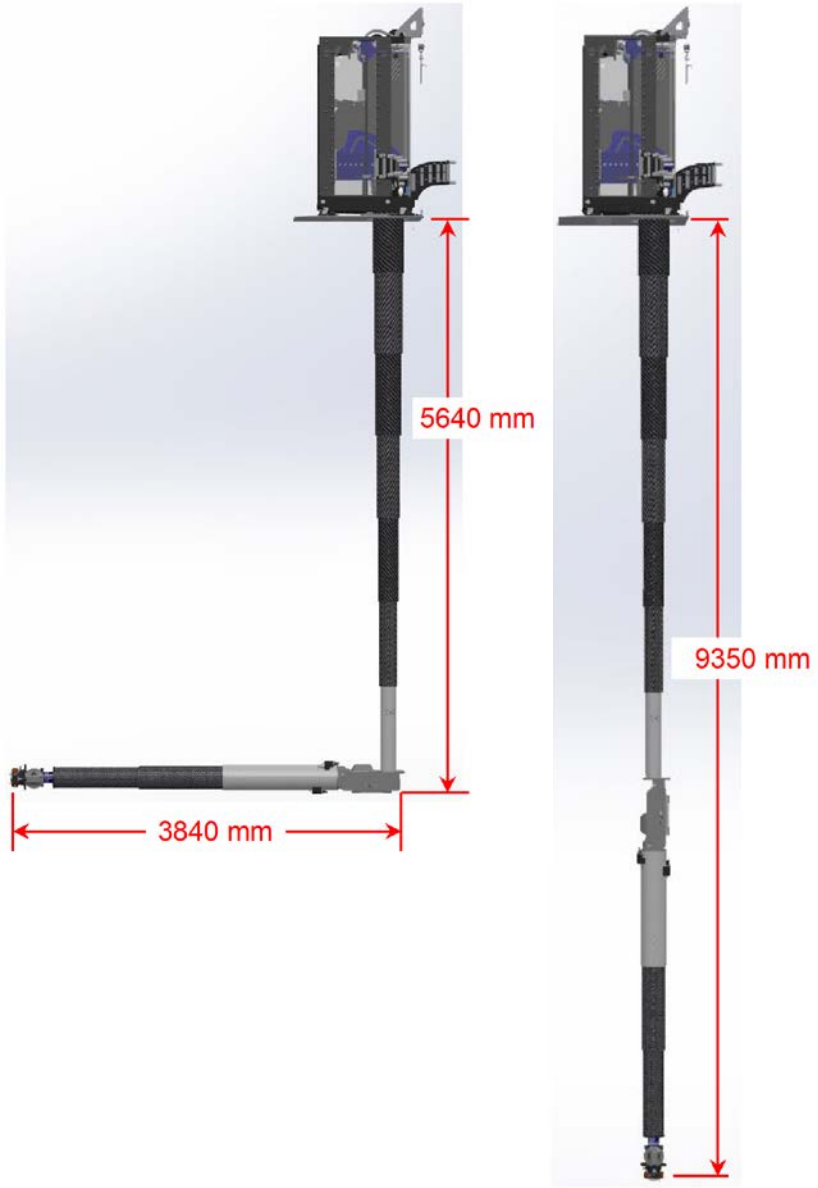

Figure 3: FRM Full Extension Length.

To prevent the spread of contamination from the contaminated area to the installation area, the FRM is equipped with both an internal and external wash down system that allows contamination to be removed from the arm during retrieval. When the arm is oriented in a vertical position the nozzles located inside the forearm and mast flush water over and through the arm.

The remote human-machine interface (HMI) station provides the controls for the FRM. The manipulator control by the FRM control system is manual, operator

initiated and controlled operations. These manual operations are vary in type (e.g. joystick control, short timer latched move), but all requires operator initiation and attention. No automatic operations of the manipulator are provided from the viewpoint of safety operations. Position sensors and force sensors are used for the various manipulator controls. Measured movements of the FRM are achieved using Inverse Kinematics. The manipulator control also provides collision detection and position sensor feedback to prevent damage to the FRM during operations. Collision avoidance is achieved by the visual feedback provided by the visions systems on the FRM and the observation camera systems located near the FRM.

The FRM does not require any planned maintenance during its expected lifecycle. The design of the manipulator is taken into consideration of lubrication, wear, fatigue, component life, minimization of hydraulic and electrical connections and ease of assembly and disassembly. The FRM is designed to be single fault tolerant for recovery. The system is designed so that the manipulator can be recovered in the event of any joint failure.

One of the strongest features of the FRM is that the arm is compactly folded inside a transport frame so that the FRM can be manually transported through the first floor of the reactor building. That allows the operators to achieve the FRM transportation and installation works in short-time and to reduce radiation exposure for the operators even a quite limited space in the first floor. After the FRM is installed above the desired floor penetration, the arm is remotely deployed through the penetration to allow for intended operations as shown in Figure 4.

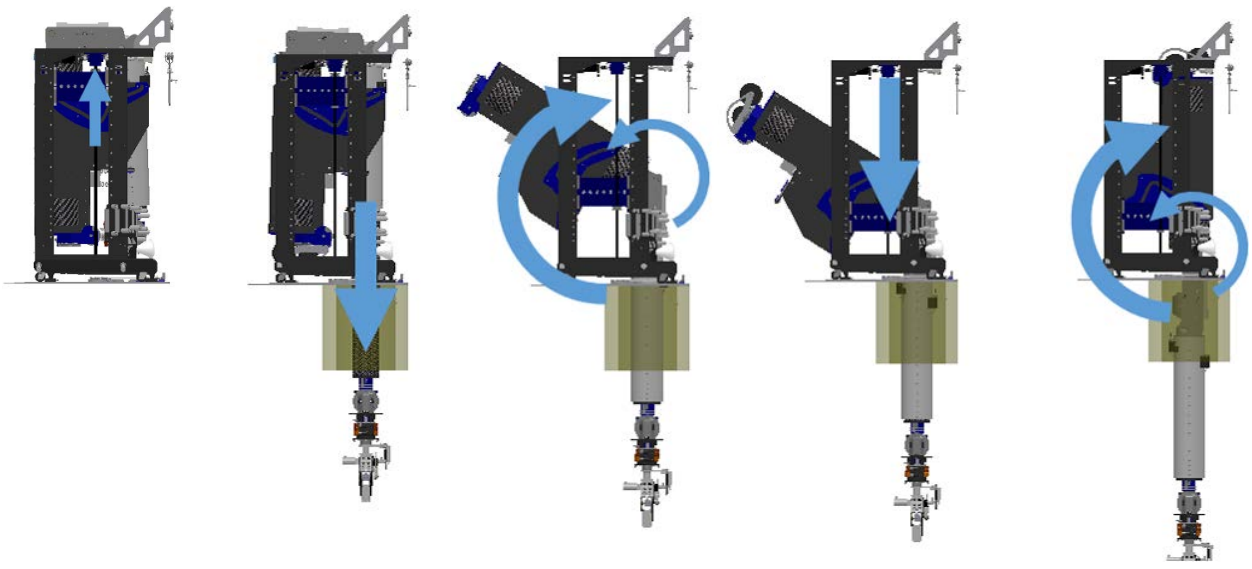

Figure 4: FRM Deployment Views

Various kinds of the tools used on the FRM were designed for specific tasks necessary to achieve the vent tube water sealing. Altogether, the tools provide access to the vent tube and suppression chamber and deploy the inflatable bag and supply water seal materials to seal the vent tube. The designated waterjet cutting tools are mainly used to remove obstacles and make access route in the torus room, the suppression chamber and the vent tube. Cut objects are steadily fixed during waterjet cutting and safely removed without dropping them off. The tool used to install the inflatable bag through the vent tube is capable of remote disconnection of the hose to the bag and sealing inlet of the bag after removal of the hose. The tool used to supply the water seal material into the vent tube also has the similar functions. The tool changer, customized off-the–shelf one for industrial robots, allows the FRM to use various kinds of tools mentioned above.

Next Step

It has been evaluated that the planned major operations using the FRM and support system were applicable to the vent tube water sealing through several functional tests as shown in Figure 5. In 2016, some improvement items found in those tests will be fed back to the equipment to provide better maneuverability and more reliability for the operations. After the improvements are finished, it is planned that the final demonstration tests for the FRM system will be performed using full-scale mockup of the suppression chamber and vent tube in Naraha Remote Technology Center located in near the Fukushima Daiichi site in the first quarter 2017.

Figure 5: Functional Tests for FRM

CONCLUSIONS

The FRM system has been developed to achieve high-level remote operations for the vent tube water sealing. This long reach remote manipulator system not only shows how it is applicable to the vent tube water sealing method for Fukushima Daiichi reactors, but also how this technology can be used to achieve various remote works in limited space and high radiation environment for the Fukushima cleanup and other D&D activities in the world.

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