Deployment of Weld Inspection Manipulator for RPV upper shell welds of TAPS-1&2

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Abstract

The reactor pressure vessel (RPV) of TAPS-1&2 is made up of three cylindrical shell courses and spherical cap shaped bottom head which are joined together with longitudinal and circumferential welds. Periodical in-service inspection of these weld joints is mandatory regulatory requirement to get relicensing for further operation of the reactor. Approaching these welds for inspection from OD side of the RPV is a difficult and tedious task. Inspection from inside surface was also not tried earlier as probes are required to be taken under water at depth of 10-12m remotely. A simplified Weld Inspection Manipulator (WIM) was designed & manufactured within short span of four months to approach upper shell welds. WIM provides automated scanning motions to the ultrasonic and eddy current inspection probes and position feedback to the data acquisition system while assuring proper contact of the probes on inspection surface which have undulations of un-machined cladding. WIM has been deployed successfully in the 22nd refueling outage of Unit#1 in July 2012 followed by Unit#2 in 2013 and again in Unit#1 in 2015, each time with improvements in areas such as automation, probes contact, co-ordinates repeatability and additional probe holders. In this article mechanical design features and operating control system of manipulator are described.

Keywords: RPV, weld inspection, manipulator, UT

1. Introduction

The Nuclear Steam Supply System of TAPS 1&2 are the second generation BWRs. TAPS 1&2 are the only operating plants among other similar design reactors built in 1960s. Assessment of RPV structural integrity is most important for ageing management and relicensing to extend safe operation of the reactor. RPV is comprised of shell and removable top head with flanges, bottom head which is welded to shell and multiple nozzles and penetrations. Vessel is made of three cylindrical shell courses. Each shell course has two longitudinal welds. Each shell course is joined together by circumferential welds. Vessel has total six longitudinal welds and four circumferential welds as shown in Fig. 1. Shell is made of low alloy steel and clad with 5.56mm (7/32 inch) thick austenitic steel weld deposits. The vessel welds are to be inspected periodically as a part of regulatory requirement. These welds cannot be approached for inspection from outer diameter side of the vessel due to the presence of thermal shield and from inner diameter side due to vessel internals. However during planned shut-down of the reactor the drier and separator assemblies are removed from the RPV top shell. As a result longitudinal (L1-1, L1-2) and their junctions with circumferential (C1) become accessible for inspection from inner side under water shield.

Manipulators for inspecting welds from ID surface of RPV for BWRs have been developed in past by GE for inspection system GERIS 2000 [1] and RPV-ID scanner [2]. These manipulators are big in size and provide circumferential and longitudinal scanning movements to the probes independent to the fuelling bridge. For weld inspection RPV of TAPS-1, a simple design of manipulator was proposed which can be quickly designed manufactured and tested before the scheduled refueling outage to fulfill mandatory upper shell weld inspection requirements. A Weld Inspection Manipulator was conceptualized, designed, manufactured, tested and deployed in the reactor to assess the integrity of L1-1 and L1-2 weld joints as well as their junctions with C1within four months period.

During inspection the manipulator is lowered under-water along a longitudinal weld to its lowest location. The manipulator then clings on to the RPV wall using permanent magnets and moves on the vessel along the weld using refuelling grappler motion. The motorized weld cleaning brush attached to the manipulator can be traversed laterally using cross travel at any location of the weld to clean the deposited materials on the heat affected zone (HAZ). Thus by operating sequentially the grappler for vertical motion and cross travel of WIM, the entire weld and its HAZ can be cleaned. Subsequently the weld cleaning brush is replaced by probe holders and the entire weld and its HAZ can be scanned using the motions of grappler and cross travel.

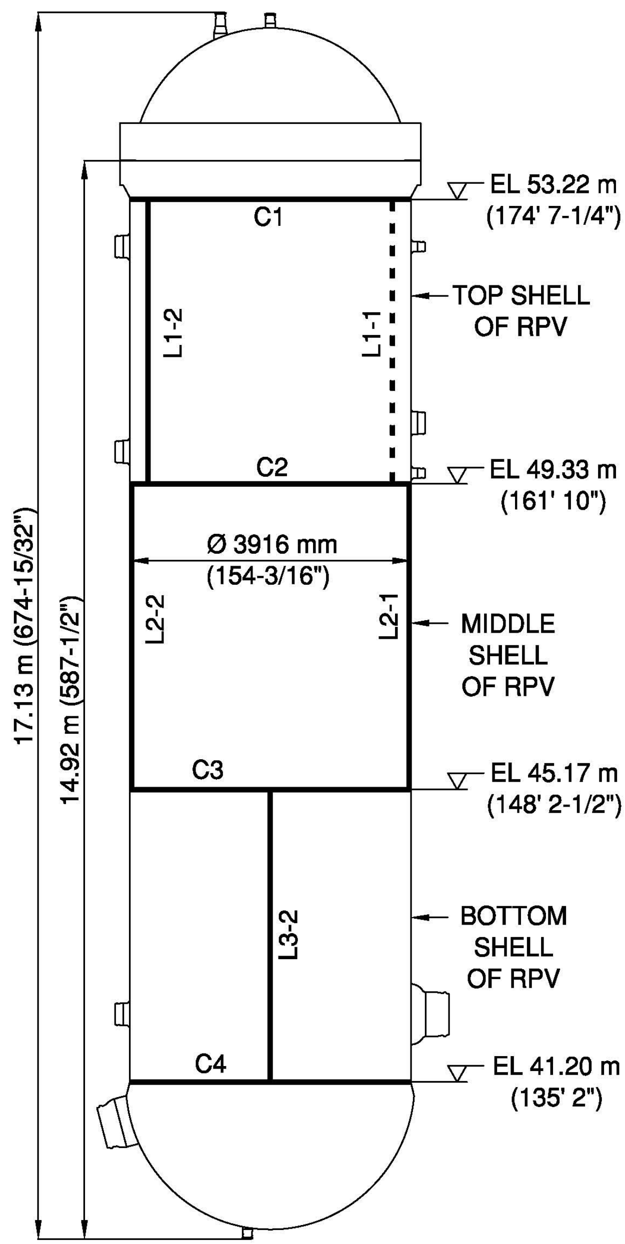


Fig.1 Schematic of RPV Welds

2. Design Description

Weld inspection manipulator is required to provide probes access to weld inspection surface and position feedback of scanned surface.To begin with a simple architecture of manipulator was conceptualized which will provide adequate contact of the probes to the inspection surface (probes decided for use was contact type suitable for unmachined cladded surface of RPV) and circumferential scanning movement.For vertical scanning movement, the motion of grappler was planned. To achieve these functions a manipulator was designed consisting of a triangular platform to house cross travel assembly on to which cleaning brush or probe holder assembly can be mounted and at top of the platform a bail compatible to fuel handling grappler for handling.The typical triangular shape allows it to be mounted on three wheels which impart enhanced stability on the RPV surface and minimum lateral traction during moving on the RPV. The seating face below the bail is meant for parking WIM using gantry at the gantry operated manipulator (GOM) stand in the fuel storage pool of the reactor building. From there it is picked up by the grappler and shifted to the cavity interconnected with it. Three wheels are mounted on the platform by taking into account the curvature of the RPV.

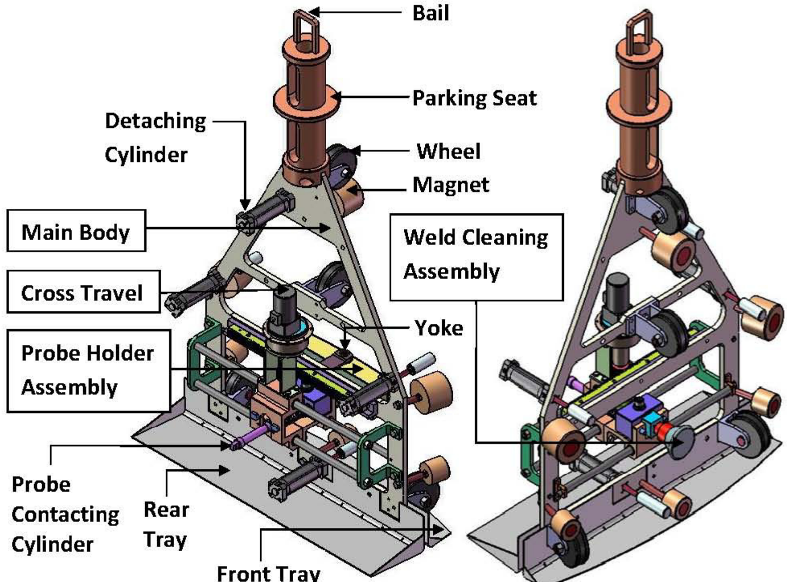


Fig.2CAD Model of Weld Inspection Manipulator

Aluminum as the wheel material protects the RPV clad surface from any scratch marks during moving of WIM. Neodymium Iron Boron permanent magnets have been mounted at six locations of the platform for clinging WIM onto the RPV. When WIM moves on the RPV the gap between front face of these magnets and RPV clad is about 2 mm. Together these magnets provide a pull-force of manipulator towards RPV which is sufficient to keep WIM clinging onto the RPV during inspection or cleaning. Four pneumatic cylinders are used to detach WIM from RPV. All fasteners are locked. Lever operated directional control valve will keep these retracted under normal condition. During extending the piston for detaching WIM, flow control valve (FCV) with metered-out connection will safeguard the RPV from any impact.

For providing circumferential scanning movements to the probe holder, a cross travel guide block housing linear bearings moveshorizontally on three guide rods(Fig. 3). Probe holder is pivoted to the block to follow the curved surface while block is driven by rack & pinion arrangement. Initially electric motor was used to drive the pinion but due to noise pick problems faced during inspection it was changed with pneumatic motor in next inspection campaign. A rotary multi turn potentiometer is used for position feedbacks. Vertical movement for scanning is through Fuelling Machine Grappler. Feedback position of the grappler is taken though encoder connected on the drive shaft of grappler.

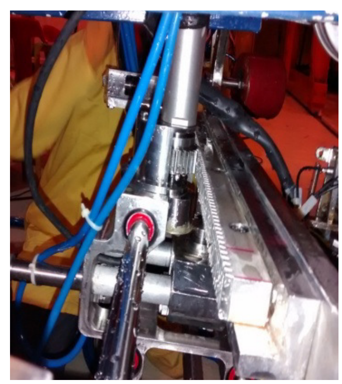
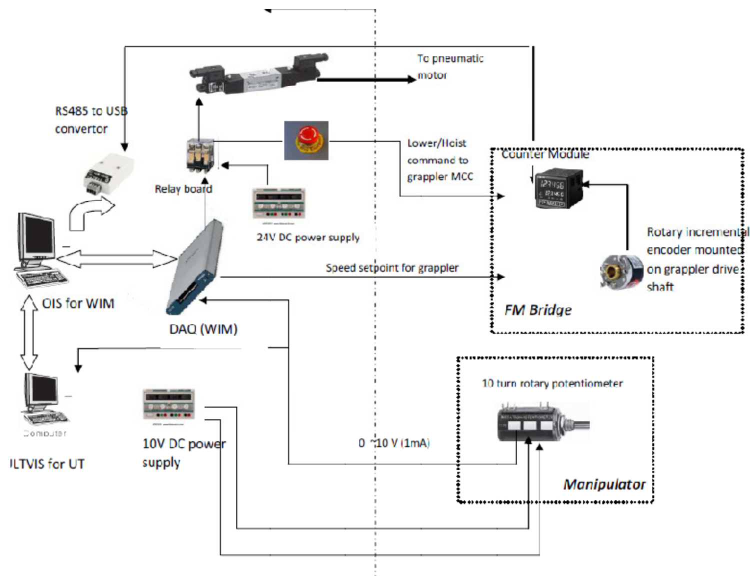


Fig.3Cross Travel Drive

A PC based control system is designed to facilitate scanning remotely. Operation of manipulator requires two motion to be controlled through remote operator interface- Horizontal motion (cross travel) and vertical motion (grappler motion). Initially electrical motor was used for cross travel and grappler was moved through manual push button and joystick of fuelling platform. In later version the electrical motor was replaced with pneumatic motor and computer control was implemented in grappler motion. Operator interface software (OIS) facilitates operation in manual mode or auto mode. Algorithm was developed and implemented to perform automated area scan with configurable index size and scan limit.The encoder signal is processed by a local programmable counter and acquired in PC through RS485 based modbus communication bus. The signal is processed through control logic programmed in personnel computer in order to generate required output to solenoid drive for pneumatic motor and to VFD for grappler motor through the data acquisition card. An emergency button mounted on the workbench near operator which trips power supply of relay connected to all these actuators and maintain safe state in case of emergency. Protection logic is implemented in the control program to prohibit movement of cross travel or grappler at extreme ends. Ultrasonic probe signal is acquired and processed by an independent data acquisition system ULTVIS. Handshake protocol through Digital Output channel of DAQ was implemented in order to establish communication between two systems.



Before inspection the surface need to be cleaned for proper UT scanning. A nylon bristled rotary brush as shown in Fig. 5 is pressed against the weld joint to be cleaned. While the air motor rotates the brush, the cross travel is indexed horizontally in steps of 10-15 mm from one end and the re-fuelling grappler pulls the WIM vertically up to clean a horizontal strip of the HAZ. The combination of cross travel of WIM and vertical motion of refuelling grappler clean the entire 500 mm HAZ al along vertical length of weld.

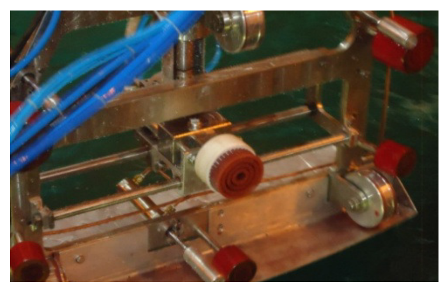


Fig.5Cleaning Brush

A set of 8 UT probes are mounted to a horizontal probe holder (Fig. 6) to detect vertical weld defects and same set of 8 probes are mounted to vertical probe holder to detect horizontal weld defects. The probe holder, made of Nylon has its front face shaped to the curvature of RPV for perfect contact. It can freely swivel about the yoke pin and automatically adjust its contact with the RPV irrespective of the position of the cross travel guide block. It houses 8 UT probes for flaw detection each for a peculiar purpose. Selections of the inspection techniques & probes done by Quality Assurance Division, BARC have been described elsewhere. The individual probes are spring loaded so that

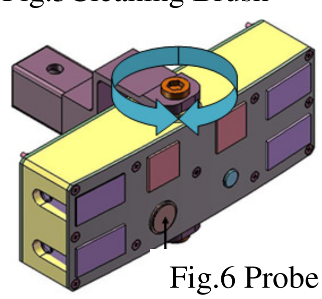


Fig.6 Probe Holder

each of them is in complete contact with RPV. The contact between probe holder and RPV is made using a pneumatic cylinder.

3. Qualification of WIM

For functional testing& qualification of WIM, a test set up to simulate RPV with less wall thickness and SS clad surface was required. It was made by rolling two plates of carbon steel and SS 304 as per RPV curvature. The plate representing clad was backed by the plate representing RPV and both plates were supported on a vertical support structure as shown in Fig 7. Standard notches were machined at several locations of the SS 304 clad which acted as reference notches for demonstrating the notch sensing capability of WIM with UT probes Performance testing of WIM was carried out in the supplier's premises. All functional aspects like clinging on test setup wall using magnetic force, moving on test setup wall, pressing the probe holder against test setup wall by probe contacting cylinders, horizontal scanning of HAZ by cross travel, cleaning action of brush by air motor, sensing the reference notches by UT probes and detaching from the walls by advancing the detaching cylinders were successfully demonstrated at shop floor before dispatching to the site.For qualifying WIM for reactor use, it was shifted to the Additional Away From Reactor (AAFR) fuel storage pool of TAPS 1&2. AAFR has facilities like refuelling grappler for handling WIM, Gantry Operated Manipulator (GOM) stand for parking WIM in the pool and 12m depth of water. These facilitate handling and testing of WIM in reactor simulated conditions. The capabilities of WIM for weld inspection were demonstrated by immersing WIM in the pool with the same test setup as used in the supplier's premises and reference standard notches were successfully detected.

Fig.7 Test Set Up with Manipulator

4.Deployment in the Reactor& Further Improvements

WIM was finally deployed to the reactor for implementation in Unit #1. Welds L1-1, L1-2 and their HAZ were cleaned by weld cleaning brush (Fig 8). UT scanning of these welds and their junction with C1 were successfully carried out (Fig. 9). It takes about 5 hrs for cleaning a longitudinal weld, 8 hrs for scanning by vertical probe holder and 16 hrs for scanning by horizontal probe holder.

During qualification & inspection in unit#1, problem of noise picking up in the probe signals and jerky cross travel motion were encountered. DC electrical motor was replaced with pneumatic motor to eliminate noise pick up and the bronze bush was replaced with linear ball bearing to solve the jerky cross travel in the upgraded version WIM (MK2). It was also qualified in AAFR before deploying in Unit #2 for RPV weld inspection.

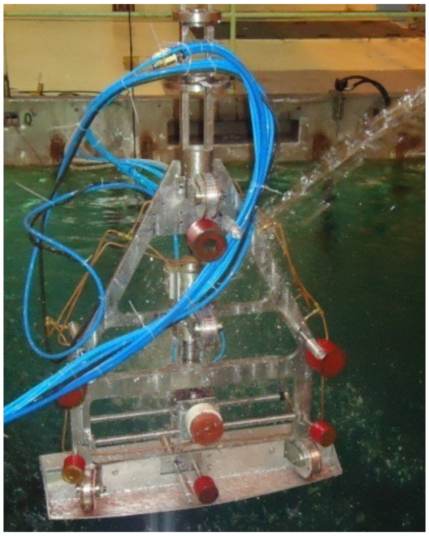


Fig. 8 WIM with Cleaning Brush

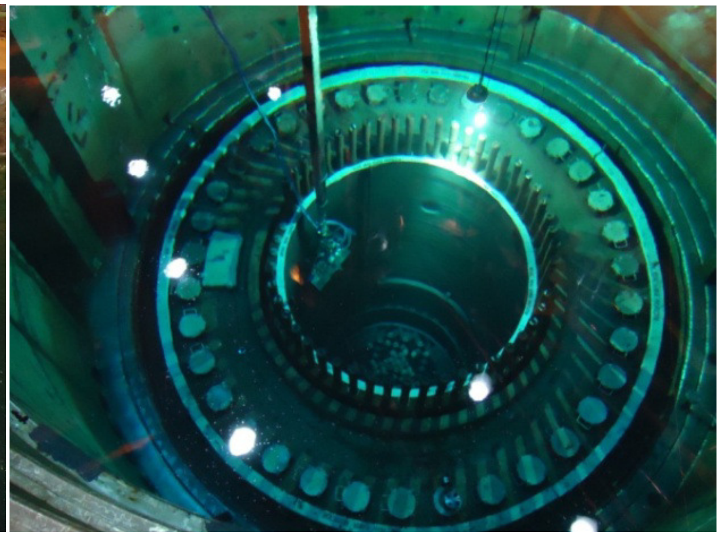


Fig. 9 WIM Performing Inspection

After data analysis of Unit#2 inspection by WIM-2 it was found that the manipulators drifts and some places probes contact is not proper. The reason for drift was steam nozzles as the manipulator passes near to the nozzles magnetic attraction force was getting disturbed. The improper probe contacts were due to large ripples in the clad surface. Drift problem was solved by providing a guiding structure to the manipulator vertical movement. Probe holder design was made more flexible to accommodate large ripples of clad while maintaining contact. Later an eddy current probe was also added to the probe holder and a new TOFD based probe holder was also designed and used in the recent inspection.

5. Conclusion:

Reactor pressure vessel weld inspection of TAPS 1&2 was a long pending regulatory requirement. In the refuelling outage of TAPS-1 in July 2012 weld inspection of L1-1, L1-2 as well as their junctions with C1 weld were successfully carried out from inner side of TAPS-1 RPV. Subsequently Unit #2 upper shell welds were inspected with upgraded version of WIM (MK2). Manipulator was further modified to eliminate drift, improve contact by more flexible probe holder design and to enable area scanning. This development is the first of its kind inspection for RPV of BWR. This has helped the site to fulfill its commitment of RPV weld inspection for the first time in TAPS history.

6. Acknowledgement

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