Design & Development of Advanced Drive Machine for coolant channel inspection of 540 MWe PHWRs

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Abstract

Periodic In Service Inspection (ISI) of Pressure Tubes of PHWRs is a regulatory requirement to demonstrate their fitness for service. Pressure tubes are susceptible to various degradation mechanisms, which are reflected by various parameters. These multiple parameters are monitored using inspection tools developed for the purpose. Currently available tools are semi automatic, require human intervention at reactor face and offer limited length of inspection head, requiring multiple visit of tooling for comprehensive monitoring. Monitoring of multiple parameters in minimum time with minimum exposure to operating personnel is vital for capacity factor of the plant. Design of Delivery Equipment for inspection tools is governed by above requirements. Advanced Drive Machine (ADM) for 540 MWe PHWRs is designed for delivering inspection tool into the coolant channel meeting above design goals. The machine is mounted on top of Fuelling Machine Bridge. After installation, machine is operated remotely from a control room and inspections are carried out without any human intervention. ADM has features for auto alignment, clamping with the channels, two stage telescopic ram and synchronized cable feeding mechanism. AC servo motors are used as actuators for various drives and meet the positional accuracy requirements. The striking feature of ADM is use of split plug, which allows entry of 102 mm diameter inspection head and makes the machine compact by avoiding need for magazine. Machine also has capability of delivering maintenance tools like sliver sampling tool, in-situ property measurement tool, replica tool etc. The machine is designed, manufactured and tested in reactor simulated conditions.

1. Introduction

Pressure Tubes (PT) which contain fuel bundles, are critical components of the PHWRs. In Service Inspection (ISI) of the PT of coolant channel assemblies is essential to ensure healthiness and to know the degradation trend of PT for continuation in service. PT undergoes various degradation mechanisms [1] such as irradiation induced creep and growth, deuterium ingress and changes in material properties due to irradiation. To monitor degradation of the PT various parameters such as volumetric examination of PT and its rolled joints, wall thickness, sag, axial creep, gap between PT and the calandria tube, garter spring position and its internal diameter are measured. For monitoring of these parameters multiple inspection tools and their delivery mechanism have been developed. Some of current generation systems being used are BARC Channel Inspection System (BARCIS) [2] for the measurement of various degradation parameters, Wet Scraping Tool (WEST) for measurement of hydrogen ingress [3] etc. Use of
these tools involves human intervention at reactor face and multiple visits by these tools for comprehensive assessment of degradation parameters.

Advanced Drive Machine (ADM) for 540 MWe PHWRs is designed to meet requirements of ISI and to eliminate human presence at the reactor face. ADM can deliver inspection tools having length of 1.5m into the channel. Inspection tools are modular in nature and these modules can be interchanged manually depending upon parameters to be monitored. This paper explains the aspects of the mechanical design of the ADM for driving inspection tools. Design of inspection tools and data acquisition system is not in the scope of this paper.

2. **Description of ADM**

ADM is mounted on the top of Fuelling Machine (FM) Bridge as shown in the Figure 1. Mounting of ADM is done such that it approaches the maximum number of channels, does not hamper functioning of FM and makes quick & easy installation. ADM mainly consists of split plug, snout assembly, telescopic ram assembly, linear rigid chain drive and mounting frame.

2.1 **Split Plug**

An innovative Split plug concept is used for providing entry of inspection tools into the channel in the reactor shut down condition. Use of this plug makes design of ADM compact as need of magazine to store the plug and inspection tools is avoided. FM replaces normal seal plug with split plug in the target channel after de-fuelling the channel as shown in the Figure 2.
After replacement of plug by FM, ADM is aligned and clamped to the target channel for inspection. Front portion of the inspections tools latches to the inner part of split plug while entering into the channel. Plug operating mechanism releases inner part of the split plug from the outer body, which remains installed in the endfitting of the channel.

2.2 **Snout Assembly**

Clamping of the ADM on channel and leak tight joint with channel is achieved by snout assembly. It has features for alignment with channel also. Alignment is achieved in two stages using head antenna & UT sensors. LVDTs are used for correcting yaw and pitch of the channel. Snout assembly consist of jaws driven by nut and screw mechanism, screw driving motor, clamping barrel, head antenna with glass switches, UT sensors and LVDTs. Face type elastomer seal is provided in clamping barrel which makes leak tight joint with endfitting.

2.3 **Mounting Frame**

Mounting frame (fig 3) is structural part of ADM and houses drives for X movement (along the FM Bridge), fine Y movement and Z movement (along the channel). Coarse Y movement is achieved by FM bridge movement.

The ‘X’ drive is rack and pinion arrangement. The rack along with the rail is supported on the top of FM Bridge. The pinion with its drive is mounted to the trolley which is made up of three plates supported on each other by linear motion blocks & guides. The trolley is kept on FM bridge on X- guide rails. Linear actuator provides ‘Z’ movement towards the endfitting. One end of the actuator is connected to the trolley and other end is joined to the Z table. Two linear actuators supporting the ram assembly provide fine ‘Y’ and pitch movement for the alignment of the ADM to the channel. Curved guide rails are provided in trolley to give ram assembly yaw movement. Yaw movement is achieved by anchoring snout of ADM to the endfitting and then giving ‘X’ movement to the ADM.
2.4 Ram Assembly

The ram assembly consists of two stage telescopic rams, called as inner ram and outer ram, driven by linear rigid chain as shown in Fig. 4. Rotation module is mounted at the back of inner ram for providing rotary motion (clockwise and anticlockwise rotations to avoid twisting of cables) to the inspection tools. Inner ram is connected to the linear rigid chain along with the umbilical cable. Modular inspection tools are connected on channel side of inner ram. A calibration tube is provided between snout assembly and ram assembly. It houses inspection tools in home position of rams. Ram assembly is designed to provide 10.5 m linear travel with ±1.0 mm positional accuracy to the inspection tools. It can push inspection tools through a channel having sag up to 50 mm. Elastomer sealing is provided in all possible leakage paths. The ram assembly provides linear speed from 0.5 mm/sec to 25 mm/sec and rotary speed from 0.5°/sec to 10°/sec to the inspection tools.

![Fig.4: Schematic of Rotating Mechanism with linear rigid chain](image)

Linear rigid chain used for driving the telescopic rams. AC servo motor with gear boxes is used for driving linear rigid chain. Use of drive motor enables achieving desired position speed control for split plug operation and inspection requirements. At the top of ram housing, special chain housing has been provided for storing the chain. Umbilical cable is connected to inspection tools through water tight connector. Cable is never exposed to water environment. A cable reel arrangement is provided to store/feed cable during outward/inward movement of ram.

3. Control System

A PLC based control system is used in order to facilitate remote operation of ADM from a control room located approx 100 meter away from operating environment. The machine consists of nine electrical actuators to provide motion to its components. These actuators move in a defined sequence for achieving desired functionality of machine. Six of these actuators are AC
servo motors and others are stepper motors. These motors are equipped with their own programmable drive to control speed and direction as per requirement. Drives are programmed to provide accurate position control as per position set points and encoder feedback to perform close loop operation. A Programmable Logic Controller (PLC) based control system with PC based SCADA interface was developed mainly to provide sequential control of each drive, check permissive, incorporate safety logic and operation interlocks. PLC communicates with motor drives through digital communication bus. Sensors located at different component of ADM are interfaced with controller for monitoring operation parameters and generating safety interlocks. The control system can be represented using following block diagram:

The PLC logic consist control modules for functionalities of Auto channel alignment, Cable reel synchronization, Axial and Rotary motion profile during different mode of inspection, Encoder position retainment. Man Machine Interface (MMI) was developed using standard SCADA package to provide operator friendly Graphical User Interface (GUI).
4. **Performance Evaluation of ADM**

ADM is manufactured and tested at reactor simulated conditions. A test set up was fabricated to simulate reactor conditions. It consists of pressure tube, endfittings and the water hydraulic system to pressurize the channel. ADM integrated with its control system was tested for sequential operation. Dummy inspection head was used during testing. Movements of machine, position control of its drives, clamping operation from control system were found to be functioning well. In next phase, qualification of machine along with inspection head is taken up before deployment in reactor.

![ADM clamped to end fitting of test set up.](image)

Fig. 6: ADM clamped to end fitting of test set up.

5. **Conclusion**

Advanced Drive Machine is developed to enable delivery of multiple tools remotely into the channel for ISI which will save considerable man-rem and reactor shut down time. The machine offers automation of operations at reactor face during In Service Inspection, which will reduce chances of human error. Design validation of the machine has been completed successfully in test setup simulating reactor conditions. Qualification trials for reactor use are in progress.

**References**

2. Puri R K., Singh M., “In-service inspection system for coolant channels of Indian PHWRs Service Inspection”, *Seventh CNS Conference on CANDU Maintenance, Toronto, Canada*, November 2005