INSTRUMENTATION & CONTROL SYSTEM FOR UNDER SODIUM ULTRASONIC SCANNER OF PFBR

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ABSTRACT

In the three-stage programme of Department of Atomic Energy (DAE), the second stage envisages the construction of Fast Breeder Reactors (FBRs). In the first phase, 500MWe Prototype FBR (PFBR) is being constructed at Kalpakkam, TamilNadu. PFBR is sodium cooled pool-type nuclear reactor which has sodium-submerged 181 Fuel-Subassemblies (FSA) in the core of the reactor. During normal operation of the reactor, the temperature of liquid sodium is more than 550°C. Due to high temperature, prolonged irradiation and flow of liquid sodium, there is a possibility of growth and protrusion of FSAs. Since, ultrasound is the only modality for visualisation inside the optically opaque liquid sodium, an automated, Under Sodium UltraSonic Scanner (USUSS) has been designed & developed for detection of growth and protrusion of FSAs, during shut-down state of PFBR when the temperature of liquid sodium is 180°C. Ultrasonic Pulse-Echo mode and C-Scan imaging technique is employed to detect growth and protrusion of FSAs. To scan the core of PFBR, sodium compatible ultrasonic transducers of 5MHz are employed for downward viewing operation for detection of growth in FSAs located underneath the scanner, whereas sodium-proof ultrasonic transducers of 1MHz are utilised to scan in lateral (i.e. sideways) direction for detection of protrusion of FSAs, in the reactor vessel. The Instrumentation & Control (I&C) system of USUSS is categorised as a non-nuclear safety (NNS) system and is primarily a PC based, automated, 8-channel ultrasonic instrumentation system with windows compatible GUI software. The system software has a provision to compare current data with the reference/base-line data. Subsequent to the confirmation of absence of an objectionable growth and protrusion of FSAs, clearance would be provided for rotation of rotating plugs, required for safe fuel handling operation. The paper provides details of I&C system of USUSS, system hardware, experiments and results.

Keywords: Prototype Fast Breeder Reactor, Under Sodium Ultrasonic Scanner, Under Sodium Viewing, Ultrasonic Instrumentation, Automated Mechanical Scanner, Protrusion Detection, Ultrasonic Transducers.

I. INTRODUCTION

In the Prototype Fast Breeder Reactor (PFBR), all the 181 Fuel Sub-Assemblies (FSAs) are supported vertically on a grid plate and are submerged in a pool of liquid sodium. During reactor operation, the temperature of liquid sodium is more than 550°C. Due to high temperature, prolonged irradiation and flow of liquid sodium, there is a possibility of growth and protrusion of FSAs and surrounding sub-assemblies (SAs). The Under Sodium UltraSonic Scanner (USUSS) is employed to detect such anomalies and provides clearance for safe Fuel Handling (FH) operation by using ultrasonic imaging technique. The USUSS consists of ultrasonic transducers, automated mechanical scanner, 8-channel ultrasonic instrumentation hardware and system software to visualize the region of interest inside the inner vessel of PFBR by using ultrasonic C-Scan imaging technique and pulse-echo mode.

The automated under sodium scanner is deployed during the shutdown campaign of reactor when the temperature of liquid sodium is 180°C. Initially the scanner is mounted onto port-I. Using four Downward Viewing Transducers (DVTs) of 5MHz, detection of highest ‘dummy’ SA located underneath the port-I is carried out. Subsequently, the transducer holder is parked 10mm above the highest SA. After completion of the parking of USUSS at appropriate depth, four Side Viewing Transducers (SVTs) of 1MHz are used to scan in lateral direction, the 100mm inter-space between core-plenum and bottom of thermo-well sleeves for detection of protrusion of FSAs/ SAs. There are in all eight DVTs and four SVTs mounted onto the transducer holder. A set of four DVTs are used for actual scanning and an additional set of four DVTs are used for redundancy. In case, the information acquired from port-I for detection of protrusion...
is inadequate, the scanner is removed from port-I and is placed onto the port-II. At port-II, the scanner is parked 100mm above the core-plenum and detection of growth in 19 FSAs located underneath the port-II is carried out using four DVTs. After quantifying the growth of FSAs w.r.t. core-plenum, the highest FSA is located and subsequently, the transducer holder is brought down to 10mm above the highest FSA. Through the 100mm inter-space region between core-plenum and bottom of thermo-well sleeves, the FSAs/ SAs are viewed sideways for detection of protrusion, with the help of four SVTs.

II. SYSTEM DESIGN

I&C of USUSS is configured into three industrial racks namely Control & Drive (C&D) Panel; Industrial PC (IPC) Panel and Ultrasonic Pulser-Receiver (UPR) Panel. The system software installed in the industrial computer provides interface to C&D and UPR panels in order to perform automated data acquisition. Display, storage and analysis of 1D, 2D and 3D data are carried out by modules of system software. Fig.1 shows a schematic block diagram of the complete I&C hardware of the USUSS. Brief description of panels, sub-systems consisting of electronics hardware, front-end transducers, automated scanner and system software is described below.

A. UPR Panel: The UPR panel houses eight channels of Ultrasonic Pulser Receiver for excitation of eight ultrasonic transducers (four of 1MHz type and four of 5MHz type). Maximum length of cables between the UPR panel and each transducer is 30 meters (inclusive of MI cable and 50 Ohms co-axial cable). The 8-Ch UPR unit receives the reflected echo signals for each channel, it amplifies and multiplexes them and sends the multiplexed echo signal to IPC panel through co-axial cable for data acquisition and processing/display/storage and analysis. The data acquisition is synchronized by generating suitable trigger signals within the UPR unit and the multiplexed trigger signal is connected to the IPC panel. The multiplexed trigger and serial RS232 signals are connected to IPC panel through multimode Fibre Optic link, in order to convey them over a long distance.

B. IPC Panel: The IPC panel houses an industrial PC, PCI digitizer card for data acquisition and the system software. IPC communicates with the UPR panel on a serial link, for synchronization of data acquisition as well as diagnostics of the UPR unit. There is an Ethernet link between IPC panel and the C&D Panel for motion control of the Z and θ motors of automation and related status checks. IPC also communicates with the Distributed Digital Control System (DDCS) server through a separate Ethernet link, for receiving current location/coordinates of rotating plugs for the purpose of proper storage of image data and uploading/downloading the acquired data to/from DDCS server for storage/retrieval.

C. C&D Panel: The C&D panel consists of control and drive electronics for driving the Z and θ motors of automation. Three phase output signals from the motor drives are connected to Z and θ motors along with the DC voltage required for built-in brakes of Z and θ motors. Two limit switches and one home position proximity detector have been provided for Z motor whereas, a proximity detector is provided for home position of theta motor. Incremental rotary shaft encoders of Z-Theta motors shall form inputs to the C&D panel. C&D panel is connected to the IPC panel through an Ethernet link, for receiving automation commands from and sending status information to personal computer. The distance of C&D panel from the automation can be up to 50 meters and distance of C&D panel from the IPC panel can be up to 10 meters.

D. Ultrasonic Transducers: Ultrasonic PZT transducer works on the principle of piezoelectric effect and is used to transmit/receive the ultrasonic energy in a pool of liquid sodium at 180 C. Eight DVTs and four SVTs are mounted on the conical shaped transducer holder. Co-axial cable connections between UPR and transducers are routed through a high frequency, low noise, cascaded slip-ring units.

Fig. 1 : Schematic block diagram of I&C system of USUSS for PFBR
E. Automated Mechanical Scanner: The automated mechanical scanner of the USUSS is a tall and slender structure consisting of two detachable parts known as the lower and the upper part. The lower part of the scanner consists of a mechanical scanner, long length spinner tube and transducer holder assembly. The upper part contains the automation assembly, which consists of two motors (for rotational and linear up/down motion of spinner tube), motion feedback elements and slip-ring units. Cascaded two Slip ring units are part of the upper part of scanner and are placed between the theta motor shaft and spinner tube. Slip-ring units prevent entanglement of co-axial cables between transducers and the instrumentation while acquiring automated C-Scan images. The lower part of the scanner with long length spinner tube is deployed inside the reactor vessel where its lowermost 3/4th part is immersed into the liquid Sodium and remaining 1/4th portion remains in hot Argon (core-cover) gas. Bottom of the spinner tube is welded to the transducer holder. The transducer holder houses twelve ultrasonic transducers, namely eight DVTs and four SVTs.

F. System Software: Windows-XP based system software has been designed to provide ultrasonic data acquisition, C-Scan imaging, automation control, growth monitoring of FSAs using DVTs and detection of protrusion of FSAs using SVTs, TOF/distance measurement, data/image analysis with reference to the base-line data/image. Under the control of a host computer, ultrasonic scanning, data/image processing and interface to DDCS server of PFBR for data/image storage/archival are carried out.

III. COMPLIANCES FOR I&C SYSTEM

All the 19" racks and electronic sub-systems are qualified for environmental compliances as per ISO9000 standards. Similarly for EM/EMC compliances, IEC61000 standards are followed for emission and immunity tests.

IV. CALIBRATION SETUP

An under-water test-setup has been fabricated for the calibration of 8-Channel Ultrasonic Instrumentation System. 10m long pipe-assembly consists of five nos. of MS pipes, each 2m long, which are leak-proof sealed between the intermediate flanges and blind flanges at both the ends, as shown in Fig.2. Horizontally placed pipe assembly is filled to its 3/4th level with water. A circular opening designated as ‘Transducer Port’ has been provided to mount the SVT at one end of the pipe. A rectangular cut-out designated as an ‘Observation Port’ has been provided at the other end of pipe for access to place the FSA top-heads made of SS. FSA top-heads (10 nos. and 90 mm tall) and reflector sub-assemblies (3 nos., 88 mm OD and 190 mm tall) are placed over the flat plates resting inside the pipe curvature. Three cylindrical shaped reflector SAs are placed behind the cluster of 10 FSAs. Circular discs are placed under the FSA top-heads to simulate protrusion in the range of 5 mm to 50 mm with a step-size of 5 mm. Provision has been made to change the orientation of protruding FSA with respect to the front surface of SVT in the range of ±30° with 5° step-size. The detection of protrusion is carried out in under-water setup where the protruding FSA was kept at a distance of about 9.5m from the SVT. Cluster of nine FSAs are kept between the protruded FSA and SVT to form the core-plenum. The actual height of hexagonal shaped FSA of PFBR is 4.5m tall whereas for calibration of 8-channel ultrasonic instrumentation system, hexagonal shaped FSA top-heads of 90mm height were used. Considering the velocity of ultrasound in sodium and water, 6m distance in liquid sodium is equivalent to 10m distance in water and therefore, the pipe assembly of 10m length was selected.

Fig. 2 : GA of 10m long pipe Assembly for under-water experiments
7. CONCLUSION

The 8-Channel ultrasonic imaging system has been designed, developed and tested at ED, BARC using 10m long pipe assembly set-up for under-water detection of 25mm to 50mm protrusion of one of the FSA top-heads located at about 9.5m away from 1MHz transducer.

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