Development of Indigenous Ultrasonic Data Acquisition and Recording System for ISI of Pressure Tubes of PHWR

S. MOITRA¹, S. K. LALWANI¹, R. K. JAIN¹, Gurpartap SINGH², A. KADU² and Anita BEHERE¹

¹Electronics Division, BARC, Mumbai, India
²Division of Remote Handling and Robotics, BARC, Mumbai, India

Email: smoitra@barc.gov.in

Abstract: In Service Inspection (ISI) of Pressure Tubes (PT) in the Indian Pressurized Heavy Water Reactors (PHWR) is mandatory as per the regulatory requirements for detection of flaws as well as dimension measurements along its full length, to assess the structural integrity for safe reactor operation. Ultrasonic Testing (UT) technique is employed for this purpose. An ultrasonic data acquisition and recording (DAQ) system has been indigenously developed to carry out ISI of PTs in Indian PHWRs. The system comprises of multi-channel ultrasonic data acquisition hardware, capable of exciting & acquiring data from the UT probes (line focus/ point focus/ parallel beam) mounted on the BARCIS (BARC Coolant Channel Inspection System) head, and data acquisition/processing/recording software. 6 UT probes are used during ISI of PTs; 2 for detection of flaws (circumferential, axial), 2 for, 1 for thickness and 1 for measurement of ultrasound velocity of coupling media i.e. heavy/light water. The PC based DAQ system acquires the real-time A-scan data from the user selected probe and stores the acquired data in the hard disk of the host PC for offline data analysis. GUI based software provides facility to configure various system parameters and display A-scan waveforms in either RF or rectified mode on the host PC monitor. Due to 100m long cables between Ultrasonic Pulser Receiver (UPR) and UT probes, noise gets coupled to the weak received echo signals. The DAQ software uses temporal averaging and digital band pass filters with user configurable parameters to remove this coupled noise. The DAQ system has been developed and qualified using underwater test setup comprising of BARCIS head, 100m long cables and calibrated PT sections with reference flaws (axial/circumferential notches and nodules). This paper describes the hardware and software features of the system and results of its qualification trials.

Keywords: Ultrasonic Testing, Data Acquisition, In Service Inspection, Ultrasonic Pulser Receiver, Pressure Tube, PHWR.

1. Introduction:

The Pressure Tubes (PT) hold the fuel bundles in Indian Pressurized Heavy Water Reactors (PHWRs). During reactor operation, they are subjected to nuclear radiation, high pressure, temperature and flow of heavy water. Due to prolonged use under these severe operational conditions flaws may appear in the pressure tube and/or it may tend to physically deform. Mechanical deformation may be in the form of increase in ID, reduction in WT and change in shape from circular to oval. Presence of flaw and/or excessive deformation may cause operational difficulties of the nuclear reactor. ISI of pressure tubes is mandatory as per the regulatory requirements for detection of flaws as well as dimension measurements along its full length, to assess the structural integrity for safe reactor operation. Ultrasonic Testing (UT) technique is employed for this purpose. For last several years, BARCIS (BARC Coolant Channel Inspection System) tool along with flaw detector is being used for ISI of PTs in Indian PHWRs. It employs 6 UT probes; 2 for detection of flaws (circumferential, axial), 2 for, 1 for thickness and 1 for measurement of ultrasound velocity of coupling media (heavy/light water). It has been growing need to store the ISI results for data analysis as well
as for long term archival to assess & understand the flaw growth and tube deformation mechanisms over its prolonged use. An ultrasonic data acquisition and recording (DAQ) system has been indigenously developed at Electronics Division, BARC for ISI of PTs in Indian PHWRs and to store the ISI results for offline analysis and archival. The DAQ system has been qualified at Division of Remote Handling and Robotics (DRHR), BARC using under water test setup comprising of BARCIS head, 100m long cables and calibrated PT sections with reference flaws (axial/circumferential notches and nodules). This paper describes the features of indigenously developed ultrasonic DAQ system, test setup and results of qualification trials.

2. Ultrasonic DAQ System Architecture and Main Features:

The ultrasonic DAQ system comprises of indigenously developed multichannel Ultrasonic Pulser Receiver (UPR) [1] unit, 400MSPS Digitizer and GUI based software. Main features of each component are given below.

2.1. Multi-channel Ultrasonic Pulser Receiver (UPR): The UPR is based on modular architecture and can have upto 8 channels of pulser-receivers. It employs microcontroller, DDS (Direct Digital Synthesizer) and CPLD (Complex Programmable Logic Device) for generating the transducer excitation signal of desired frequency/PRF/cycles. In all, it has 4 dual channel pulser-receiver modules, 1 multi channel sequencing module, 1 HV generation module. All the modules are interconnected using a double Euro backplane. Other features are:
   a) Each UPR channel can be configured for pulse-echo or through transmission mode.
   b) Each pulser channel can generate, through software control, single negative pulse of variable width or burst of unipolar negative or bipolar high voltage square wave signal of desired frequency and number of cycles for excitation of ultrasonic transducers.
   c) Each receiver channel has independently controlled Programmable Gain Amplifier (PGA). Receiver outputs are multiplexed using 8:1 multiplexer.
   d) Serial interface for parameters’ control through PC.
   e) Amplified echo and trigger outputs are provided for interfacing UPR to the digitizer.
   f) Dimensions : 19” x 6U x 320mm (D)

2.2. COTS Digitizer: The PC based digitizer used in the DAQ system has the following main features:
   a) Selectable Sampling rate up to 400 MSPS
   b) Trigger: External/ Self.
   c) ADC resolution: 8 bits.
   d) Programmable acquisition delay and number of samples.
   e) Programmable Buffer size: Up to 128kB.
   f) Host PC interface: PCI.
2.3. **Control and DAQ Software**: Figure 1 shows a screenshot of the GUI based control and DAQ software which runs on the host PC. The main features of the software are as follows:

a) Control and configuration of the UPR and digitizer parameters

b) Synchronization of the UPR unit and digitizer in order to achieve data acquisition and display from selected channel.

c) A-scan display and measurements in RF and rectified modes.

d) User configurable Range (mm), Display-Delay (mm), sound velocity, probe definition, configuration file saving/retrieval etc; independent settings for each channel.

e) Two gates to carry out online measurements (Amplitude, TOF, Distance); Size and placement of each gate using mouse; Measurements based on a single gate (A or B) or two gates (IA - BI).

f) Online measurements based on Peak or Flank method with TOF measurement resolution of 2.5-ns at 400 MSPS.

g) Single frame or continuous A-scan data recording into a binary file.

h) Data retrieval either in continuous playback or in frame-by-frame modes.

i) Online temporal averaging and digital band pass filter (BPF) implementation to improve SNR.

![Figure 1: Screen shot of Control and DAQ Software](image)

3. **Qualification Trials**:

Figure 2 shows the test setup used for the qualification trials carried out at DRHR, BARC. The test setup is comprised of BARCIS probe head (Figure 3) having 6 UT probes which are used during actual ISI of PTs. The probe head is inserted in various
calibration PTs (i.e. pressure tubes having known flaws at known locations [4]) and the assembly was immersed in water. Cable assembly of 100 meters is connected from the BARCIS head to the UPR unit channels. The receiver output of the UPR unit is connected to the digitizer placed in the host PC where control and data acquisition software (Figure 1) was installed.

![Ultrasonic DAQ system along with Test Setup used for qualification trials](image1)

**Fig. 2:** Ultrasonic DAQ system along with Test Setup used for qualification trials

![BARCIS Probe Head](image2)

**Fig. 3:** BARCIS Probe Head

### 3.1. Flaw detection

Three types of reference flaws were present on the calibration PT sections. They are circumferential notches, axial notches and nodules. The depth of reference circumferential and axial notches is 2% of the PT wall thickness (66μm in PT of 220MW reactor) [4]. Nodules were artificially grown on the PT and were typically 100 microns in diameter having a diffused non uniform structure. The probe used for axial scan detects circumferential flaws and the probe used for circumferential scan detects axial flaws. Figures 4 and 5 show the A-scan waveforms obtained during circumferential and axial flaw detection respectively. Figure 6 shows the A-scan for nodule detection. In these figures, the echo of interest is the one which is shown within the gate (red colour); all other echoes are geometric signals.
Fig. 4: A-scan waveforms obtained from circumferential notch: a) OD notch at half skip distance, b) OD notch at one & half skip distance, c) ID notch at zero skip (direct hit) and d) ID notch at one skip distance.

Fig. 5: A-scan waveforms obtained from axial notch: a) OD notch at half skip distance, b) OD notch at one & half skip distance, c) ID notch at zero skip (direct hit) and d) ID notch at one skip distance.
3.2. **PT Wall Thickness measurement:** Figure 7 shows two consecutive backwall echoes obtained from the calibration PT using the spot focus probe. The UPR parameters were adjusted such that the backwall echoes have sufficient amplitude but not saturating. The wall thickness was measured by measuring ToF between the first two backwall echoes using two gates. The wall thickness was measured at several locations in the calibration tube having known values, measured mechanically. Thickness measurement resolution in Zircalloy tube is about 6μ. As indicated in figure 7, the measured thickness at this location of the calibration tube is 3.688mm while the actual thickness was 3.7mm.

3.3. **Measurement of Ultrasound–Velocity of water:** To measure the water path, the time of flight (ToF) is multiplied by the velocity of sound in water. Since the sound velocity changes with temperature, it is necessary to either measure the temperature of water and find the velocity from a standard look-up table or measure the instantaneous sound velocity before measuring the water path. In the BARCIS probe head, the reference
sound velocity is obtained using a step wedge (also a part of BARCIS probe head). This measured sound velocity is used by diameter measurement probes to calculate the respective water paths. With 400MSPS sampling rate, the water path measurement resolution is about 1.9µ. Time of flight was accurately measured between the two echoes obtained from the two steps of the wedge as per the existing procedure and the velocity was computed. To confirm the reading, the temperature of the water was measured and reference sound velocity was found from the look-up table. A close match was observed. The result was verified using USD15 flaw detector also.

3.4. **Internal Diameter (ID) measurement:** Two probes placed back to back along the PT ID are used to measure the ID [5], as depicted in figure 8. The probe face to face distance (X in fig. 8) is measured using the tube of known ID during calibration of each BARCIS head. During ISI, the water paths WP1 & WP2 are computed using the measured ToF and the reference sound velocity, measured in-situ. PT ID is measured by adding WP1, WP2 and X. During the qualification trials of the DAQ system, the PT ID was measured at several locations/ orientations in the tubes having known ID, as per the existing ISI procedure. Table 1 below shows the result of ID measurements along with the corresponding actual ID and the error in measurement. As seen in the table, maximum error observed is 40µ.

![Fig. 8: PT ID measurement principle](image)

Table 1: PT ID measurement test results.

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>ID Value by mechanical Method (mm)</th>
<th>Average Probe face to face distance (mm)</th>
<th>Probe 1 water path reading (mm)</th>
<th>Probe 2 water path reading (mm)</th>
<th>ID value measured by ultrasonic instrument (mm)</th>
<th>Inaccuracy (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Q (2 - 8) 82.71</td>
<td>42.57</td>
<td>18.53</td>
<td>21.62</td>
<td>82.72</td>
<td>+0.01</td>
</tr>
<tr>
<td>2</td>
<td>Q (6 - 12) 82.79</td>
<td>42.57</td>
<td>18.53</td>
<td>21.67</td>
<td>82.77</td>
<td>-0.02</td>
</tr>
<tr>
<td>3</td>
<td>R (4 - 10) 82.80</td>
<td>42.57</td>
<td>18.53</td>
<td>21.66</td>
<td>82.76</td>
<td>-0.04</td>
</tr>
</tbody>
</table>
3.5. **Inspection of Rolled Joint Area of PT:** The DAQ system was also qualified for inspection of the rolled joint area of the PT by manually moving the probe head in an underwater test setup.

3.6. **Continuous data recording and playback:** Individual A-scan files and continuous data were recorded by manually moving the BARCIS head in the calibration PT section. The data recording rate depends upon the PRF & no. of temporal averages used during the inspection. The stored data files were opened in continuous playback and frame by frame modes. SNR improvement features like temporal averaging and BPF performances were also evaluated.

4. **Conclusion:**

An indigenous ultrasonic data acquisition and recording (DAQ) system has been developed at Electronics Division, BARC for ISI of PTs in Indian PHWRs and to store the ISI results for offline analysis and archival. The DAQ system has been qualified successfully at Division of Remote Handling and Robotics (DRHR), BARC using underwater test setup comprising of BARCIS head, 100m long cables and calibrated PT sections with reference flaws. Signal quality and measurement accuracies are found to be satisfactory as per the ISI requirements.

5. **Acknowledgement:**

Authors are thankful to Dr. D.N. Badodkar, Director, RD&DG and Head, DRHR and Shri D. Das, Associate Director, E&I Group for their encouragement and guidance. Authors are also thankful to Shri Manojit Bandyopadhyay, Head ISI section, DRHR, for providing tremendous support & guidance during qualification trials of the DAQ system at DRHR, BARC.

**References:**


