Development of an Automated Scanning Mechanism for Profilometry of Pressure Tubes of PHWR

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Abstract - Automated scanning mechanisms are widely employed for ultrasonic imaging and gauging of tubes for assessment of integrity and life-expectancy. Ultrasonic instrumentation with automated scanner provides accurate and repeatablemeasurements. Indian Pressurised Heavy Water Reactor 220MWe (PHWR) has 306 coolant-channels where each channel consists of Zircaloy Pressure Tube (PT). Due to high temperature, pressure and irradiation, PT undergoesdiametral creep due to hoop stress. Based on the periodic directives of regulatory authorities, PT of a specific coolant channel is removed out and subjected to post-irradiation examination (PIE) for metallurgical studies. ED and PIED of BARC and TC&QCD, IGCAR, Mumbai have jointlydesigned and developed an automated ultrasonic gauging test facility for PIE of PT. The automated 2-axes mechanical scanner is interfaced to 5-ChannelUltrasonic Gauging System for accurate ID and Wall-Thickness measurement of irradiated PT, which is placed inside a lead-filled cask to shield Gamma radiation. During inspection process, cask is filled with water and it is placed in a tilted manner to avoid spillage of contaminated water.Linear and Rotary motions are imparted to the inspectionhead containing four ultrasonic transducers for gauging and one more transducer for on-line measurement of acoustic-velocity of water. By movement of inspection-head, profilometry of PT is carried out over the entire length. Paper describes details of the automated test facility designed and developed for dimension measurement of irradiated pressure tubes of 220MWe PHWR at BARC, using ultrasonic immersion technique and 5-Channel ultrasonic instrumentation.

1.0 Introduction

Thin walledZircaloy tubes used in critical applications such as pressure tubes of coolant channels of PHWR, are subjected to internal diameter measurementby ultrasonic gauging technique, under Post-Irradiation-Examination (PIE) program. The operating principle of ultrasonic gauging technique is based on the Pulse-Echo (PE) mode. Typical ultrasonic immersion setup for gauging of tube is as shown in Fig.1(A) and 1(B).

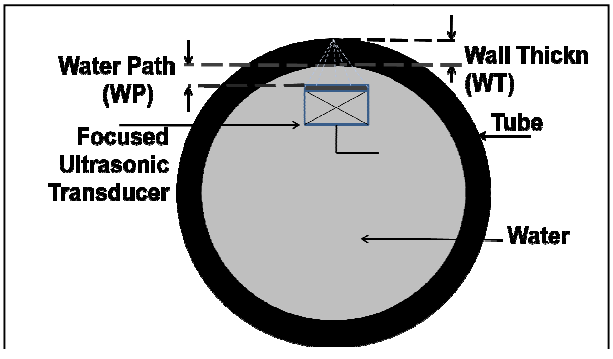

Fig.1(A)

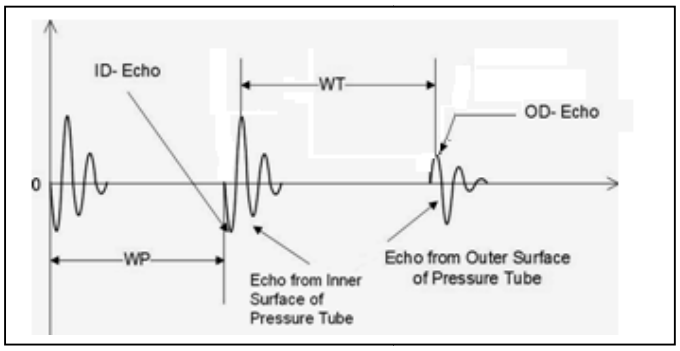

Fig.1(B)

Fig.1 Principle of Ultrasonic Gauging carried out from Inside the Pressure Tube using water immersion Technique(A) Schematic for Gauging of a Tube filled with water and (B) TOF/ Depth Measurement using ultrasonic echo signals

In the setup, focused, immersion transducers are fitted into a non-metallic transducer-holder and placed inside the pressure tube where the tube is filled with water. 10MHz, highly damped, focused, immersion transducer is energized by a high voltage spike pulser. The generated ultrasonic waves propagate through water and get reflected from the inner surface of the tube under test. Reflected echo signals are received from the water-metal interface (i.e. from ID) and from the metal-air interface (i.e. from OD). Hence Time of Flight (TOF) of the echo signals need to be measured keeping in view the phase and amplitude. The TOF is computed using the echo signal pattern, reflected from the front surface and the back surface of tube under test. In addition to measure the TOF for water path and Wall Thickness (WT), computation of ID and OD is carried out, as shown in Fig.2 and 3. Data of single pair of transducer placed 180^0 apart, enables computation across diameter of the tube.

Two pairs of transducers, which are mounted along a diameter line but 90^0 apart, are submerged into water to acquire two sets of ID, OD and WT for the same tube, as shown in Fig.2. By imparting axial and circumferential motions to the transducers holder, the tube under testingis gauged over the entire length.

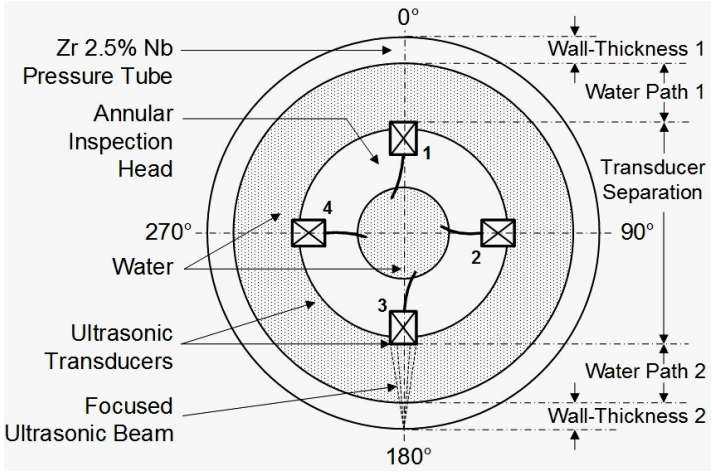

Fig.2 Gauging Setup for a Tube with Four Transducers

In the setup shown in Fig.1(A), the signal reflected from the outer surface of the tube is phase reversed with respect to the echo signal received from the inner surface, as shown in Fig.1(B). Details of PIE setup are provided inFig.5.

1.1 Inspection Procedure

The tube to be inspected is filled with water with an access from inside and four immersion transducers are placed 90^0 apart, each facing towards the ID of the tube, as shown in Fig.2.

Using combination of automated linear and rotary motions of X and Theta axesfor the inspection head, pressure tube is gauged and data for ID, OD and WT is tagged with positional values.

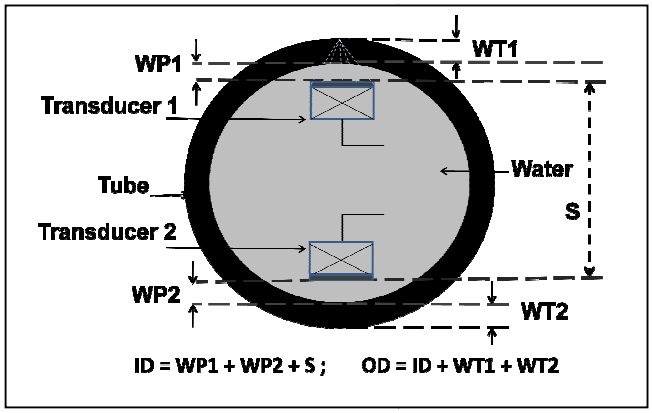

Fig.3 Schematic for Gauging of a Tube from Inside and ID-WT Measurement

2.0 System Description

The schematic block diagram of Automated 5-Channel Ultrasonic Gauging System (UGS) is shown in Fig.4. The sub-systems required for automated gauging of irradiated pressure tube consist of –

I] **Ultrasonic Instrumentation-**

* 5-Channel Ultrasonic Spike Pulser
* 5-Channel Receiver
* 100MSPS, 8 Bits Digitizer
* Multichannel Sequencer
* Serial interface of ultrasonic instrumentation to PC

II] **System Software-**

* Ultrasonic data acquisition, storage, display for 4-channels
* Measurement of TOF/ Depth
* On-line acoustic velocity correction for water with respect to temperature, using one more transducer channel
* Offline analysis of ID and WT variation

III] **Mechanical Scanner-**

* Mechanical scanner with linear and rotational motion with 0.5mm and 0.5Deg. accuracy
* Servo Control & Drive Unit
* Serial/ ETH interface of servo motor controller to PC
* Existing Manual setup - At present, the irradiated pressure tube is stored in a cask. When the ultrasonic gauging needs to be carried out, the inspection head i.e. transducer holder attached to the 6mtr long SS rod is manually inserted into the pressure tube. The manual gauging procedure takes long time. ID and WT data is collected at every 50mm for the tube under test.

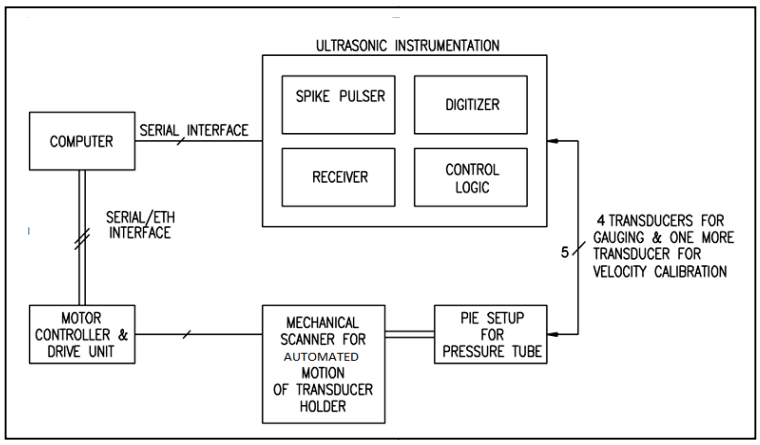

Fig.4 Schematic Block Diagram of Automated 5-Channel Ultrasonic Gauging System

2.1 System Setup and Gauging Procedure

i) Pressure Tube made of Zirconium – Niobium alloy (Zr2.5% Nb) for 220MWe PHWR, with 'as fabricated' values of ID, OD, and WT along with the tolerances are:ID= 82.55 +0.4/-0 mm; OD= 90.0 +0.5/-0 mm; WT= 3.32 +0.5/-0 mm

a) Irradiated PT is kept inside a hollow cylindrical shielding cask.

b) To avoid any spillage of contaminated water, the cask is sealed at one end by a water-tight rubber bung having outlet valve.

c) The other end of the cask is left open for insertion of inspection head along with coaxial cables for transducers.

d) With the aid of an EOT crane, the open end of cask is lifted by 15^0 and placed onto a supporting table.

e) Degassed water is filled into the cask through the open end till the whole PT is submerged in water.

f) 5.1 m long PT weighs around 50 Kg and the weight of cask is around 10 T.

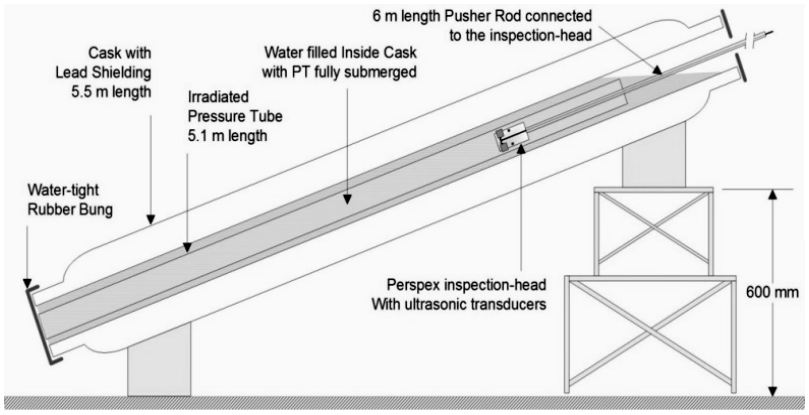

Fig.5 Cask filled with water contains Irradiated Pressure Tube and X-Thetamotions are imparted to inspection head for Gauging

g) Care is taken to have rolling plungers on the OD of inspection head to maintain the centring of the inspectionhead inside the PT.

h) Small step block and 5^{th} transducer are used to on-line compute acoustic velocity of water with reference to variation in water temperature.

i) Four transducers are mounted on the OD of the inspection head with 90° separation.

j) The 10 MHz, immersion type five transducers have focused beam in water.Grub screws are provided for each transducer for alignment. Fig.6 shows schematic of inspection head assembly.

k) Mechanical Scanner is attached to one end of the inspection head, using 6m long rod. Theinspection head is pushed/ pulled in an automated manner by providing linear and rotational movement to the transducer holder inside the PT. Fig.7 shows the photograph of automated scanning mechanism.

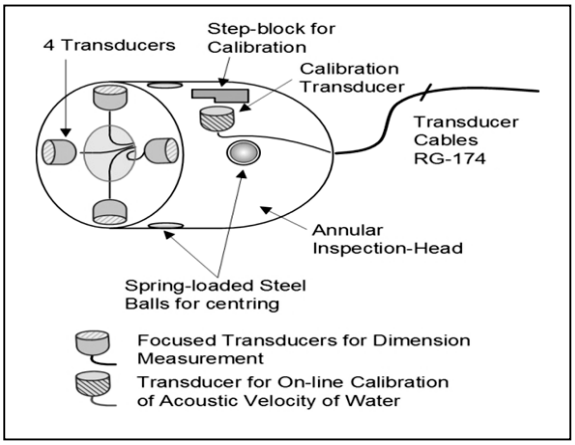

Fig.6Schematic of Inspectionhead assembly for Gauging of PT

Fig.7Photograph of Automated Scanning Mechanism

l) Using the TOF values, following computations aremade for off-line analysis, as shown in Fig.2 and Fig.3.

1. The ID of PT is computed as Water-Path of Transducer 1 + Water-Path of Transducer 2 + S, where S is the separation between front surfaces of Transducer 1 and Transducer 2.
2. Water-Path for the transducer is the equivalent distance in water and it is computed using respective TOF and the acoustic velocity of water measured by 5^{th} transducer.
3. Wall-Thicknesses measured by Transducer 1 and Transducer 2 are computed w.r.t. interfaceecho signal received from ID. The acoustic velocity of PT is a known value.

3.0 Application

Automated, ultrasonic gauging of irradiated pressure tube has appreciable benefits over manual gauging method such as,

i) The inspection head is attached to the automated mechanical scanner for repeatable measurements.
ii) Automated gauging providesID and WT data tagged with position information
iii) The gamma radiation dose is very high for irradiated pressure tube and so the automated gauging saves manREM and radiation hazards to the operating personnel.
iv) Automated gauging of various pressure tubes placed in multiple casks can be carried out using the same setup and accuracy.

4.0 Conclusion

Ultrasonic immersion technique has been used for measurement of internal diameter and wall thickness, simultaneously around the same circumference of Pressure Tube of PHWR. The variation in two parameters namely WT & ID is used to calculate Hoop stress around a

particular circumference. Two pairs of normal beam, focused transducers would be placed diametrically opposite to each other for each pair, in the inspection head.Thereforetest facility comprising of an automated, 5-Channel Ultrasonic Gauging System (UGS) designed and developed for measurement of WT and ID of irradiated pressure tubes of 220 MWe has been found useful for creep studies under Post-Irradiation-Examination (PIE) program.

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