Measurement of Annular Gap Between Pressure Tube and Calandria Tube during In-Service Inspection of 220MWe Indian Pressurized Heavy Water Reactors (PHWRs) Using Eddy Current Technique

H. M. Bapat, M Padmanabhan and Manojit Bandyopadhyay

Division of Remote Handling and Robotics
Bhabha Atomic Research Centre,

Trombay, Mumbai – 400085

Maharashtra, India

E-mail: hbapat@barc.gov.in, mpadmana@barc.gov.in, manojit@barc.gov.in

Abstract

The coolant channel of Indian Pressurized Heavy Water Reactor (PHWR)[1] is having two concentric tubes, the Pressure Tube (PT) and Calandria Tube (CT). There are four spacer rings known as Garter spring between these two tubes. At operating conditions, the PT is at high temperature of around 300°C while the CT is at a low temperature of around 50°C. Heavy water flows in pressure tube at high pressure and it takes away the heat generated due to fission reaction in fuel bundles. Thus during operation, pressure tubes are subjected to high pressure, temperature and radiation. In these operating conditions pressure tube expands in both axial and radial direction due to creep phenomena. The tube also sags in downward direction. Thus with time, the annular space between PT and CT reduces and they may come in contact with each other. If contact condition remains for a long time it is postulated that PT may fail in brittle mode. Hence it is important to periodically measure annular gap between PT and CT.

The paper describes Eddy current based technique used for measurement of annular gap between PT and CT during In-service inspection. Pancake type transmit and differential receive eddy current probe is used. The paper discusses various parameters affecting the eddy current gap signal and different methods used to eliminate the effect of these unwanted parameters from gap signal. Gap measurement results are presented at the end of paper.

Keywords: Pressure tube, Calandria tube, Annular Gap, Eddy Current

1. Introduction

In a typical 220MWe Indian Pressurized Heavy Water Reactor (PHWR) [1] there are 306 coolant channel assemblies. In one coolant channel assembly there are two concentric tubes called Pressure Tube (PT) and Calandria Tube (CT). Both tubes are separated by spacer ring called garter spring. A typical coolant channel assembly is shown in figure 1. Pressure tube is made of Zr-2.5%Nb material and Calandria tube is made of Zircalloy-2 material. Each pressure tube contains nuclear fuel and pressurized heavy water as coolant. The pressure tubes operate at high temperature, high pressure and high radiation. The zirconium alloy is susceptible to enhanced rates of creep under these operating conditions. The creep is in both axial and radial direction. This creep results in reduction of pressure tube wall thickness. Creep, self weight of pressure tube and weight of the fuel bundles are responsible for sag in pressure tubes. Diametrical creep increases diameter of pressure tube. Sag of pressure tube and increase in diameter of pressure tube results in reduction of annular gap between PT and CT. Thus with time, the annular space between PT and CT may reduce to an extent that the hot pressure tube may come in contact with relatively cold calandria tube. Because of hydrogen accumulation, such a cold spot could act as a potential location for initiation of blister and premature failure of pressure tube in brittle mode [2]. Hence it is important to periodically measure annular gap between pressure tube and calandria tube. PT-CT Gap measurement is carried out using BARC Channel Inspection System (BARCIS) [3] during In-service inspection with reactor in shutdown condition and shutdown pumps running.

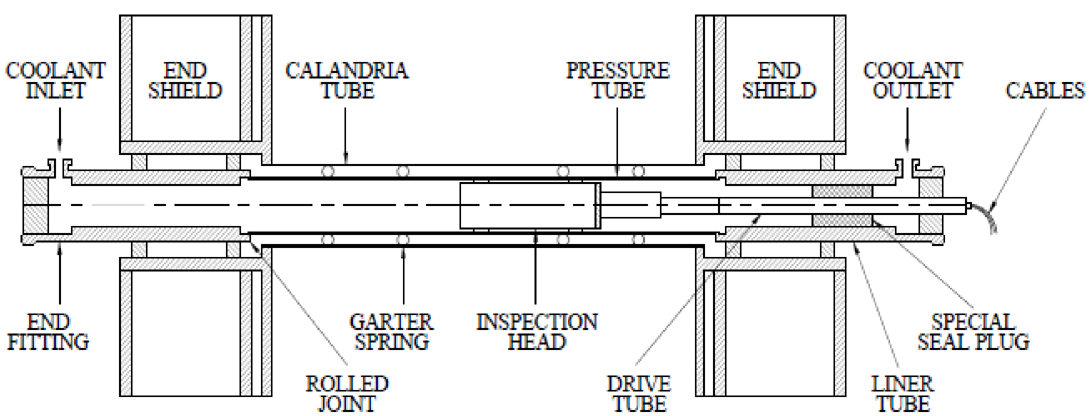

Fig. 1 Typical Coolant Channel Assembly

2. Eddy Current PT-CT Gap Measurement Technique

Eddy current probe used for measurement of annular gap between PT and CT is pancake type, transmit and differential receive probe. The probe is designed to work satisfactorily in conditions which prevail inside pressure tube during shutdown condition. The probe is hermetically sealed as it has to withstand pressure of around 5Kg/Cm2. The probe works satisfactorily in high radiation environment. It can withstand total cumulative radiation dose of 100MRads at the dose rate of 1MRad/hr. The temperature of coolant during shutdown condition is around 50 deg centigrade and the probe is qualified for working at this temperature [4]. The probe is fitted in BARCIS inspection module (figure 2) and this module is used for inspection of coolant channels.

In Gap probe there are two secondary coils placed one above other and encircled by a primary coil. The secondary coils are connected in differential mode. The operating frequency of probe is kept low because the flux has to cross the complete wall thickness of pressure tube and penetrate up to calandria tube. The probe is connected to standard eddy current tester supporting send and differential receive probe configuration.

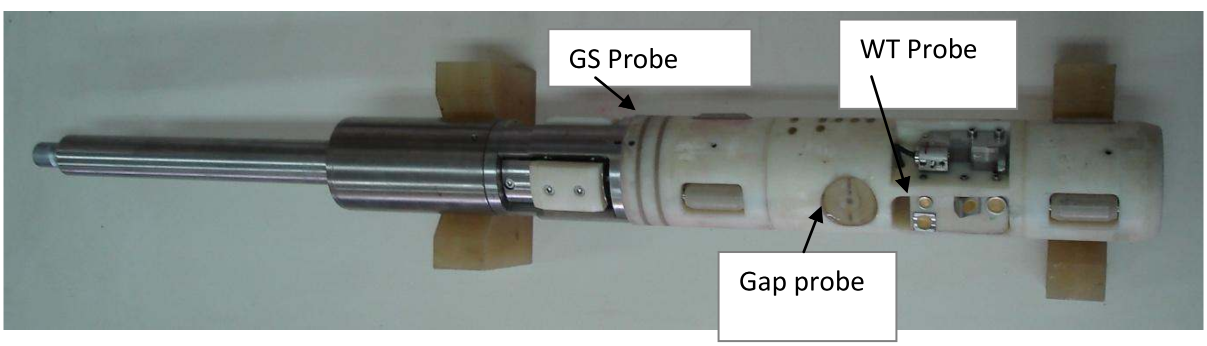

Fig. 2 BARCIS Inspection Module

3. Parameters Affecting PT-CT Gap Signal

There are multiple parameters which affect the eddy current gap signal. These parameters are Probe lift-off variations, Pressure tube wall thickness, Pressure tube electrical and magnetic property changes due to service, Temperature of coolant and Gap between PT and CT

Lift-off signal has a good phase separation with respect to gap signal. It is around 40 to 50 degrees and therefore it’s easy to eliminate the affect of liftoff by selecting proper phase for gap measurement. During measurements phase is adjusted in such a way that liftoff signal gets aligned in X-axis and measurement is carried out on the Y-axis component of the signal. By this, the effect of probe lift-off variations is nullified.

Variations in wall thickness along the length of pressure tube affect the eddy current PT-CT Gap signal. Therefore calibration data is generated for different pressure tube thickness. Pressure tube wall thickness is measured separately by ultrasonic technique and its effect is compensated during gap computation using the calibration data. Differential pick-up probe is self compensating for temperature variations except there is temperature sensitivity due to dimensional changes of probe. With reactor in shut-down condition, temperature variation along the length of the channel is negligible. Also temperature variation from channel to channel is very small. Hence, the effect of temperature on probe output is negligible. Changes in electrical and magnetic properties of pressure tube are assumed to be small and hence their effect on output is not considered. Vertical component of instrument is the gap signal which is recorded.

4. Probe Calibration

During probe calibration, phase angle of eddy current instrument is adjusted to minimize the effect of lift-off. This phase angle is kept constant during further calibration and inspection. To calibrate for thickness effect, calibration standard made of pressure tube material having different known thickness covering the entire range of thickness variation is used. Change in output for change in gap for each thickness is recorded and calibration curve is generated. A typical calibration curve is shown in figure 3. Interpolation technique is used to expand the data and generate expanded calibration data base.

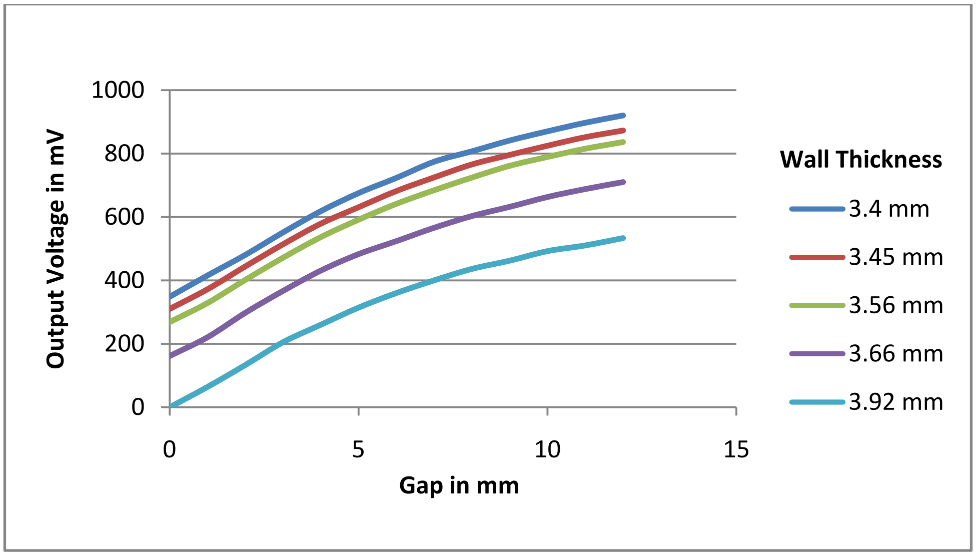

Fig. 3 Gap Calibration Curve

5. PT-CT Gap Measurement

PT-CT Gap measurement is carried out during In-service inspection of coolant channels. It is one of the many parameters of coolant channel which are monitored during ISI. BARCIS Inspection module as shown in figure 2 carrying eddy current gap probe, garter spring detection probe, ultrasonic wall thickness probe and other probes is loaded into the channel for inspection. During inspection eddy current gap output voltage and wall thickness data along 6 O'clock position are acquired at suitable intervals. Garter spring locations are also recorded.

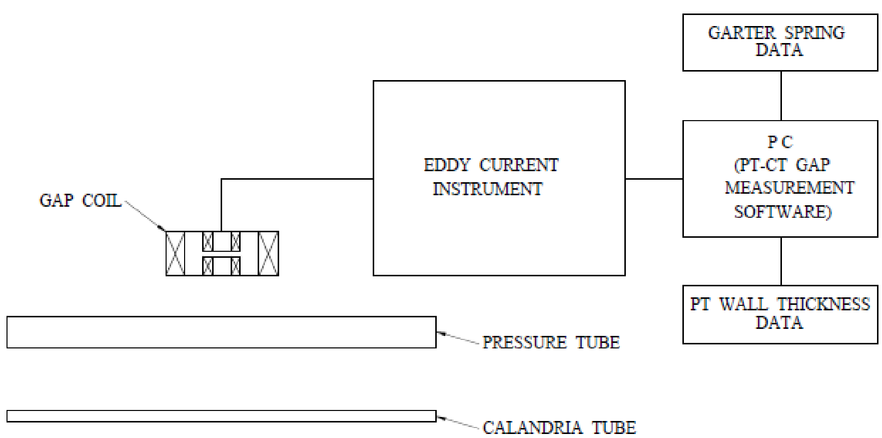

Fig. 4 PT-CT Gap Measurement System

Gap output voltage data, wall thickness data and garter spring location data acquired during inspection is fed to PT-CT Gap measurement software along with other required fields. Figure 4 shows the PT-CT Gap measurement system. It is assumed that gap at garter spring location is 7.0 mm. With gap at garter spring location as 7.0 mm and measured wall thickness, output value as per expanded calibration data base is found. This value is used to normalize all other data. With the help of measured wall thickness and normalized output values, gap profile is generated. Fig. 5 shows a typical gap profile. The gap measurement software calculates the minimum gap and gives its location. This data is very useful for further analysis and estimation of important parameters related to coolant channel life management.

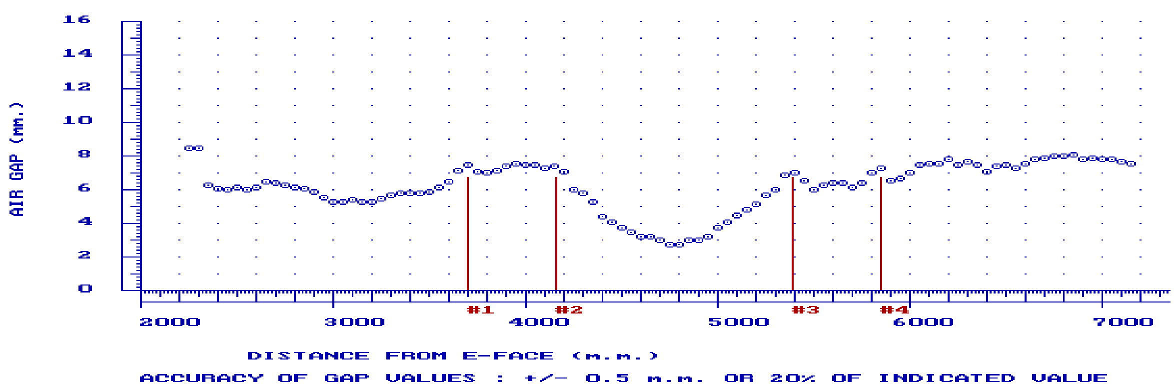

Fig. 5 Gap Profile

6. Conclusion

The paper presented eddy current based PT-CT annular gap measurement technique. This technique is used during In-service inspection of coolant channels of 220MWe Indian PHWR's. The gap data generated proved as important input for coolant channel life management.

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