In-service non-destructive evaluation techniques for structural integrity of pressure tubes of PHWRs in India

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1 INTRODUCTION

An inservice non-destructive evaluation (NDE) programme has been planned and being implemented in India to ensure safe and reliable operation of the pressure tubes (PT) of the natural UO_2 fuelled pressurised heavy water reactors. The pressure tubes are 9220 mm long (total), 82.6 mm inner dia, and 4.0 mm wall thickness Zircaloy-2 tubes positioned horizontally between two tube sheets and each of them contains 12 bundles of fuel elements. Heavy water coolant passes through these tubes which number 306 for a 230 MW reactor. Each of the pressure tubes is surrounded by a calandria tube (CT), 107.8 mm I.D and again made from zircaloy-2. The nominal gaps of 8.5 mm between the CT and PT are maintained by two (in the earlier reactors) or 4 (in the more recent reactors) garter springs, positioned in the annular gap between the PT and CT (Fig.1). The structural integrity of pressure tubes needs to be considered not only with respect to their own properties, but together with the CTs and the garter springs as well, because of the following reasons. Subsequent to the failure of a PT in Pickering-2 reactor in canada in 1983, it has been realised that the garter springs could get displaced during hot conditioning or subsequently, due to vibrations and other reasons. This displacement can cause a significant length of the PT being unsupported. Bottom part of the PT (temp. 523-583 K) then can sag down to touch the much colder CT (temp. 343 K). Massive hydrides can form due to hydrogen transport by temperature gradient. The massive and brittle hydrides in irradiated tube can subsequently lead to breach and thus loss of integrity of PT. Although there are some other mechanisms that might affect the structural integrity of the PTs, the one mentioned above appears to be the more important at present. Therefore, the schemes of the in-service inspection adopted should be able to forewarn about the possibility of the above eventuality.

2 TECHNIQUES AND SCOPES OF IN-SERVICE INSPECTION

The NDT techniques possible for in-service inspection (ISI) of pressure tubes include eddy current testing (ECT), acoustic emission (AE) monitoring, ultrasonic testing (UT) and dimensional measurements. AE technique is feasible for on-line monitoring of leaks and perhaps for crack initiation and growth as well. An accompanying paper in this seminar (Kalyanasundaram 1987) highlights the use of AE to detect and locate the leak paths in a tube sheet of pressure tube assembly. This shows that AE has the potential to monitor leaks in PTs as well. UT has been found to be feasible for detecting and locating cracks in the tube sheet region (Barat 1984). In this paper, the importance of ECT in ISI is described. The scheme of ECT for ISI of PTs should be as follows: Locations of the garter springs are determined first to find out whether they are dispalced from their specified locations. These displacements, if large, may lead to a significant length of the pressure tube being unsupported, resulting in gap reductions in certain regions. ECT is thereafter used to measure the profile of gap between PTs and CTs, with particular attention to the unsupported length. In the case of an operating reactor, a third requirement for ECT is to detect the occurance of hydride precipitation and defects in the pressure tubes which might have generated during the reactor operation.

2.1 Garter spring location

Garter springs (GS), made from a Zr-alloy, are close coiled encircling springs. The cross-sectional diameter of garter spring is 6.74 mm. A bobbin type differential probe assembly made at the authors' laboratory was found to be sensitive to detect the GS location. Test frequency of about 8 kHz was found to be optimum. This frequency corrrosponds to slightly more than (1.4 times) the standard depth of penetration (SDP) where one SDP was taken as the wall thickness of the PT.

At the GS locations, there are definite "figure of eight" patterns (with significant amplitudes) on the impedance plane on the oscilloscope screen. Angular shift of garter spring leads to variation in amplitude and phase angle (Fig.2). The accuracy of location of garter spring is better than ± 10 mm.

2.2 Measurement of minimum gap (MG) between calandria tube and pressure tube

The studies were initiated using bobbin probe (differential or absolute). Though it was possible to accurately determine the MG from 2 mm to the closure, the MG between 8.5 mm to 2 mm could not be characterised. For this investigation, the gap was varied in an experimental CT/PT assembly (test assembly) using the controlled movement of the movable platform of a tensile testing machine. The platform would move CT relative to PT.

To obviate the uncertain results while using a single probe, another approach was resorted to. In this, two differential probes connected differentially were employed. One of the probes was inside the PT of the test assembly while the other was within a reference PT surrounded by a CT (reference assembly). The CT of test assembly could be moved relative to the PT to achieve a desired variation of MG. The test frequency used was found to be optimum at 12 kHz.

At the start of the measurement, the PT and CT in the reference assembly would be made co-centric at the specified MG value of 8 mm. The ECT probe in the reference assembly and the one in the test assembly would indicate balance, if co-centricity is present in the test assembly. If not, there will be shift in the vector point in the impedance plane. The CT in the reference assembly can then be moved relative to the PT to get a null balance. MG of the reference assembly at null position is equal to the MG in the test assembly. Figure 3 shows the calibration curve for MG measurements. Accuracy of the method was found to be ±0.5 mm.

2.3 Defect detection

To standardise the method of defect detection, several circumferential and longitudinal artificial notches were introduced on the outside surfcae of the PT of a full scale assembly (Fig.1). The depths of the notches varied from 3% to 70% of the wall thickness of PT. A differential type bobbin probe was used for this study. Maximum sensitivity was found to be in the range 14-20 kHz (At 12 kHz, SDP = wall thickness of PT). It was possible to discriminate the indications due to defects upto 3% of wall thickness in longitudinal and transverse direction from those occurring due to the presence of GS, based on vector analysis.

3 CONCLUSION

Eddy current testing is considered as an important in-service inspection technique for assessing the integrity of pressure tubes of pressurised heavy water reactors. This technique can detect the garter spring locations between the calandria tubes (CT) and pressure tubes (PT). It can measure the gap between the PTs and CTs. It can also be used to detect defects in PTs. It is intended to carry out pre-service ECT complementary to UT for defect characterisation and aid to interpretations for in-service inspection. In this paper, the methodologies for these measurements as practised in India have been highlighted.

4 FUTURE WORK

Planned work includes: Detection of hydrides by ECT; development of sector probes for defect and hydride detection; detailed signal analysis for differentiating the anomalies; enhancing reliability and establishing complementary nature of dimensional measurements and ECT for gap characterisation and development of automated system for ISI.

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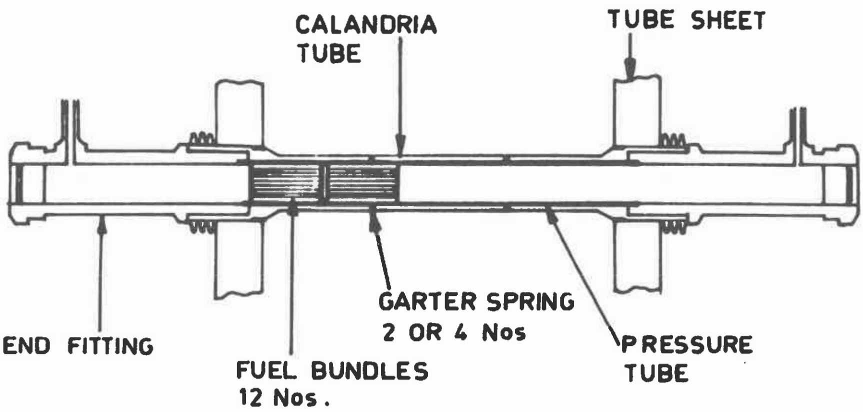

Fig.1. Schematic sketch showing pressure tube/calandria tube assembly of pressurised heavy water reactors.

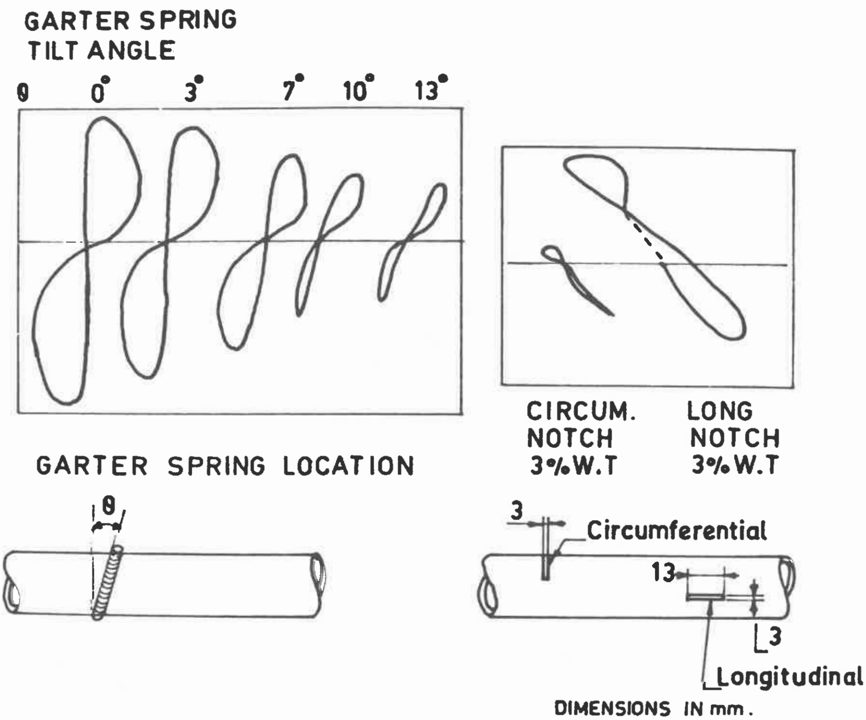

Fig.2. Impedance plane indication of

(i). The presence of garter spring between pressure tube and calandria tube and

(ii). Defects in pressure tube.

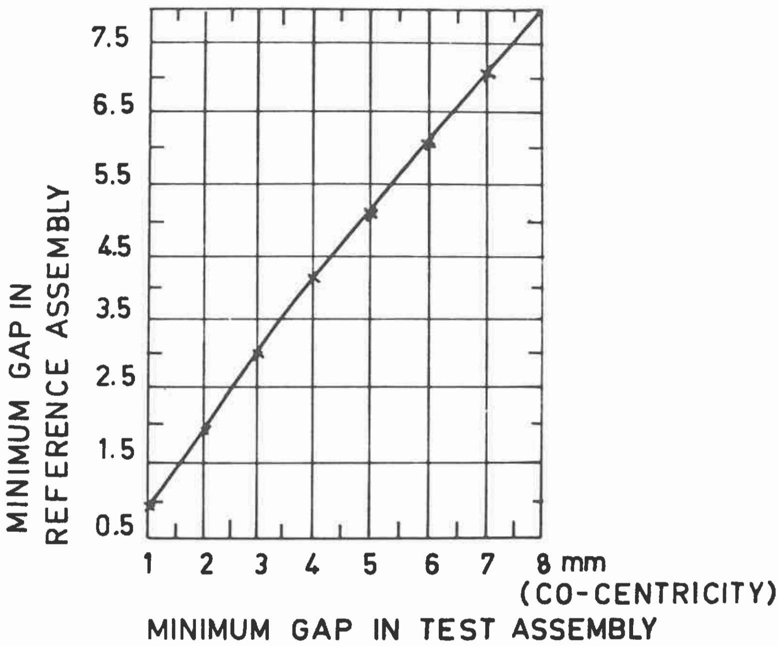

Fig.3. Calibration curve showing the relationship between the gap in the test assembly and the gap in reference assembly.