Detection of blister formation and evaluation of pressure tube/calandria tube contact location by ultrasonic velocity ratio measurement technique


Radiometallurgy Division
Bhabha Atomic Research Centre

Abstract

Presence of hydrogen in zircaloy pressure tube affects the velocity of ultrasound propagation. Both longitudinal wave velocity ($V_L$) and shear wave velocity ($V_S$) are affected depending on the concentration of hydrogen. Velocity ratio ($V_L/V_S$) changes as per the concentrations of hydrogen in different locations along the length of pressure tube. A hydride blister which forms at the pressure tube and calandria tube contact point is a distinct zone containing hydrogen 2-3 order of magnitude more than the parent matrix and hence, can be detected by sharp change in velocity ratio.

Introduction

WATER CORROSION OF ZIRCALOY PRESSURE tube produces hydrogen/deuterium (H/D) during reactor operation. Some fraction of this hydrogen is absorbed throughout the length of pressure tube. In case of contact between pressure tube (PT) and calandria tube (CT), hydrogen absorbed in the matrix migrates to the contact region (cold spot) under thermal and stress gradient. Over a length of time a point is reached when hydrogen concentration in the contact zone exceeds terminal solid solubility (TSS) limit and zirconium hydride platelets begin to precipitate. The localised concentration of massive zirconium hydride is termed as "Blister". With time the blister grows in size and when it reaches a critical size it can crack. Presence of a cracked blister is a matter of concern for the safety of pressure tubes. Therefore, effort is to be made to detect the blisters using non-destructive technique before it grows to a critical size and cracks.

The measurement of ultrasonic velocity on pressure tube without accurate measurement of thickness can
be misleading. Thickness variations are present in the as manufactured pressure tubes. To avoid the effect of thickness variations, the velocity ratio (VR) technique have been adopted to detect blisters. This paper discusses the work carried out and result achieved at Radiometallurgy Division, BARC.

**Ultrasonic testing technique**

A 10 Mhz point focussed probe was used under normal incidence immersion condition to get 3-4 backwall echoes. A high frequency damped ultrasonic transducer which gives few oscillations is well suited for time of flight measurements. Normal incidence is achieved by maximising the signal coming from water/pressure tube interface. This is done by adjusting the probe and monitoring the signal on the screen. Fig.1 shows CRT screen photograph of typical ultrasonic echo pattern. The peaks A, B, & D are multiple backwall echoes produced by longitudinal wave trips. Peak C is by mode converted one way shear wave. The water column length between pressure tube surface and ultrasonic probe is adjusted such that shear wave peak C has maximum amplitude. The time of flight is measured with CRT screen fully expanded. The difference in time of flight (TOF) of C&B and D&B are measured in nanoseconds to calculate the ratio of the two velocities using derived correlation (1). The velocity ratio for unhydrided zircaloy is 2.05 and 2.8 for hydride blister.

Velocity ratio $V_L/V_s = 1 + 2 \times \frac{(C-B)}{(D-B)}$                      \hspace{1cm} (1)

![CRT screen echo pattern for velocity ratio measurement](image)

**Scanning setup and measurement**

The pressure tubes removed from the reactor are highly radioactive. A Lead shielded cell was constructed to carry out the velocity ratio measurement on irradiated pressure tube. A vertical water tank fitted with window was used to immerse pressure tube piece containing the pressure tube calandria tube contact locations. Perspex ring probe holder was fitted on a tripod inside the tank. A focussed normal probe was used for VR measurement. Two other probes were fitted for axial and circumferential flaw detection in the pressure tube wall. The pressure tube piece held by internal collet was translated up/down by a special pulley and drum arrangement with flexibility to rotate it by 360°. Counter weight was provided to balance the pressure tube piece weight for an easy and controlled movement. Interior of the cell was lightened by WOW electric bulbs. The visibility of contact locations was enhanced under immersion in water free from air bubles. Through the window it
was possible to see the probe being accurately positioned on the contact locations while taking the measurements.

Fig.(2a) shows photograph of contact locations and Fig.(2b) shows the velocity ratios measured over different locations on the K-7 pressure tube. Measurements were taken in the centre of contact patches and on surrounding areas by moving the pressure tube both axially and circumferentially. As can be seen, velocity ratios at contact locations are not different from that at surrounding areas which has about 30 ppm hydrogen/deuterium. This indicated that contact locations do not contain any blister. This was later confirmed by neutron radiography and metallography. Large number of measurements were taken but for brevity only few measured values are shown in the adjoining sketch Fig.2b.
Discussion

In a focussed beam peripheral longitudinal rays fall at an angle and get mode converted to shear wave. Shear wave signal appears separately due to its lower velocity. The amplitude of shear wave peak depends on crystal diameter and focal length. Wider the focussed beam cone, higher will be the amplitude of shear wave peak. Mode converted shear wave signals are normally weak. Shear wave signal should not disappear due to variation in water column, surface morphology and curvature. Peak A keeps changing its shape because it comes from pressure tube/water interface therefore should not be considered for VR measurements.

Velocity ratio measurement corresponds to the average H/D concentration over the (thickness) point of inspection. Over the contact zone only a surface layer may reach blister composition, which will not give VR 2.8. Even then the average H/D concentration will be very high to give a detectable increase in VR.

When the velocity ratio measurements are done from inside the pressure tube, a stronger shear wave peak C is obtained because concave curvature further focusses the beam which will be an added advantage. The disadvantage of carrying out VR measurement from inside is that it becomes a blind operation and further ID surface may have thick oxide with cracks and scratches which may affect signals.

Conclusion

The measurement carried out did not reveal any sharp change in velocity ratio at pressure tube and calandria tube contact zone compared to their surrounding areas. This indicates that no blisters have formed at the pressure tube calandria tube contact zone. This was also confirmed by neutron radiography and metallography. This technique will be refined by measurements on more number of pressure tubes removed from the reactor.

Acknowledgements

The authors would like to acknowledge the work done by the staff of Post Irradiation Examination Section for carrying out this work. The authors would like to thank Mr D.S.C. Purushottam, Director, Nuclear Fuels Group, for his encouragement and appreciation of this work.

References

1. Mair H.D., Moles M.D.C., and Dolbey M.P. The experience of uncracked blister detection in Bruce nuclear station, IAEA consultants meeting on the effect of hydride blisters on the integrity of PHWR pressure tubes, 25-29 July 1994 Vienna.

2. Gangotra S., et. al. Neutron radiography of contact location of irradiated zircaloy pressure tube from RAPS -II, 14th WCNDT Dec.8-13, 1996 New Delhi INDIA.