IV Conferencia Panamericana de END
Buenos Aires – Octubre 2007

Pressure Tubes Blister Detection by NDT

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Abstract

In the framework of International Atomic Energy Agency Coordinated Research Programme on Inter-comparison of Techniques for Pressure Tube Inspection and Diagnostics CRP: I3.30.10, five countries have participated in an inter-comparison of inspection and diagnostic techniques, in use and under development, for characterization of HWR pressure tubes during their service lifetimes. Participants have collaborated to investigate the capability of different techniques to detect hydride blisters that can form on pressure tubes during their service. The intent has been to identify the most effective pressure tube (PT) inspection and diagnostic methods, and to identify further development needs. This work presents the job carried out by CNEA laboratories. The Hydrogen Damage Group prepared samples with Blisters on PT sections that were characterized by Ultrasound (UT) and Eddy Currents (EC).

1. Introduction

Blisters Formation (BF) is one of the most probable failure mechanisms of long time in service Pressure Tubes of CANDU type HWRs. BF is originated by thermal gradients. Specifically, cold spots such as those originated in the neighbourhood of a PT/calandria-tube (CT) contact area have, in the past, conducted to growing and cracking of blisters and subsequent crack propagation and fracture of Zry-2 PT. In CANDU reactors, the PT/CT contact is produced by displacement of garter springs from their original position. In Modern CANDU reactors this problem was solved, nevertheless in the olders, Embalse HWR for example, the contact took place in many PT´s. Then, it is important, from the point of view of safety, to have a means to detect blisters during in-service inspection.

BF needs a minimum hydrogen or deuterium (H&D) concentration in the material to progress. Estimation of H&D content in irradiated zirconium alloy components of HWR's is essential for performance evaluation, failure analysis and validation of computer codes to ensure safe, continued operation and life management of the reactor. The prediction of the crack rate in blister nucleation and growth in the contact zone of PT and calandria tube requires the knowledge of the terminal solid solubility (TSS) of hydrogen in Zr. Therefore, it is of great interest to be able to determine the H&D present in the component, by Non Destructive Techniques (NDT) and TSS.

Some NDT techniques can be used for blister detection. However, the sensitivity and the reliability of these techniques need to be demonstrated. With this objective a co-ordinated research program was sponsored by IAEA. No commercial standards of hydrogen/deuterium in zirconium alloys exist. The tasks included the development of such standards in support of reliable hydrogen/deuterium measurements. This is considered a key item and would be very useful.

Laboratories from Canada, Korea, India, Romania and Argentina have participated in an inter-comparison of results. Argentina and India prepared samples for all laboratories and different measurements and detection techniques.

For hydrogen determination, the assessed techniques were: Inert Gas Fusion (IG), Hot Vacuum Extraction Mass Spectrometry (HVEMS), Ultrasound (UT) and Eddy Current (EC). Temperature for hydride dissolution and precipitation were calculated with Differential Scanning Calorimetry (DSC), Differential Thermal Analysis (DTA) and Resistivity. Blisters were evaluated by UT and EC.

This work reports the job made by the Argentine team for the formation of blisters in PT sections and the detection and characterization of the blisters by means of UT and EC methods.

2. Experimental Work

2.1. Blister Formation

All the samples were cut from a section of PT supplied by Canada. These specimens were then submitted to conditions which result in the accelerated formation of blisters. The steps necessary to produce blisters on PT sections are three:

a) Hydriding by cathodic charge
b) Homogenization annealing.
c) Diffusion of the H in a thermal gradient.

2.1.1. Hydriding by cathodic charge:

Hydriding is necessary to increase the hydrogen concentration and accelerate the blister formation. The electrolytic hydriding was made on the inner surface of the tube without removing the surface oxide. Only annular sections ~100 mm diameter and 25 mm long were charged because of the Power Supply limitations. The cathodic charge conditions were: Anode: Pb, electrolyte: 0.05M SO_4H_2, current density > 210 mA/cm^2, temperature: 70 - 95°C. As a result, a hydride layer is formed on t he specimens surface.

2.1.2 Homogenization annealing.

In order to dissolve the hydride layer an electrical furnace was introduced inside the PT. The tube was wrapped with a ceramic blanket (Durablanket ®). Along the tube the temperature was 385 – 410 ºC, the hydride layer is expected to be entirely dissolved inside the PT. The duration of the thermal treatment was the time necessary for the diffusion of the H through the thickness. As a result, an annular section with a homogeneous H distribution is obtained.

2.1.3 Diffusion under Thermal Gradient.

To obtain a hydride blister, i.e., a small region with a very high hydride concentration, a thermal gradient is produced on a localized zone of the PT surface, because H would diffuse towards the cold area. Fig. 1 shows a scheme of the device employed to produce this thermal gradient. The PT section is internally heated with the electrical furnace. A water refrigerated aluminum block is pressed on the sample by means of a spring. The tip of the block is interchangeable, so that contact with different shapes (rectangular or circular) and sizes dimensions can be produced.

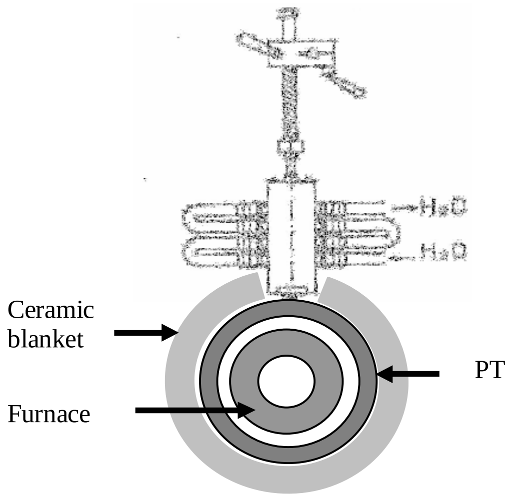


Fig.1. Device to form hydride blisters by thermal gradient.

2. 2. NDT Blister detection

2.2.1 Eddy Currents

A MAD8D equipment from Eddy Current Technologies inc. was used for blister detection. Tests in the impedance mode were performed at 270 kHz on the outer surface with specially tailored curved probes made from rectangular planar coils. Eddy current tests from the inside were carried out to simulate the in-situ inspection. To select the inspection frequency, a standard skin depth equal to tube wall thickness (4.5 mm) was assumed. Tests were made at frequencies in the range 3.0 to 30 kHz in the impedance mode with especially prepared probes, which could be adapted to wall curvature.

2.2.2 Ultrasound

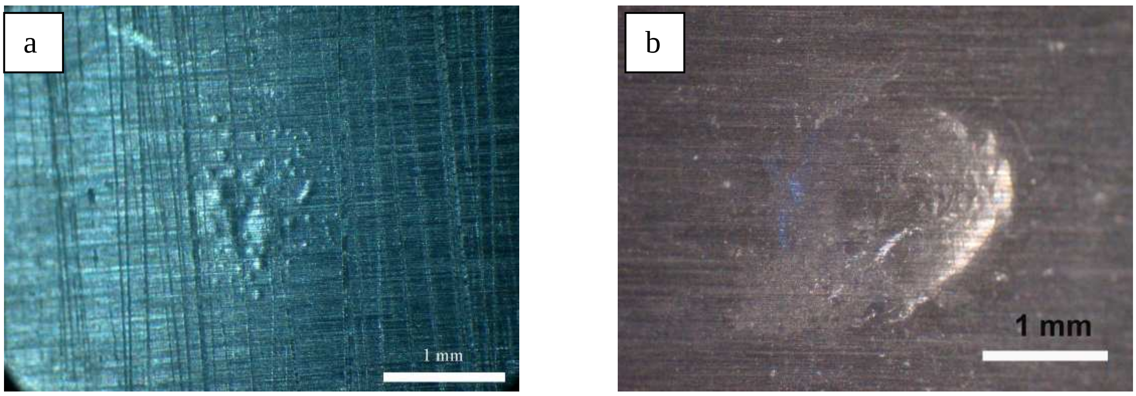
A NEUS 8.80 Multichannel Ultrasonic Equipment with 4 transducers from STAVELEY NDT Technologies, HI-437, 10 MHz, 38 mm focus, 0.25” were used.
Reference sensitivity, reference chart: CSA standard ID and OD flaws.
Techniques: Shear wave Pulse - Echo
Transducers 1 and 2 detect circumferentially oriented defects.
Transducers 3 and 4 detect axially oriented defects.

3 Results

3.1 Blisters characterization

3.1.1 Macrography

A first characterization of the blister was made with low magnification optical microscope. Macrographs of the blisters are shown in Figs. 2. The macrograph in Fig. 2 a) correponds to sample (C1 a) which presented a cluster of little blisters and that in Fig. 2 b) is a well formed blister in sample (C2 b).



Figs 2. Blisters a) C1 a and b) C2 b

Diameter of blister (C1 b) was less than 1 mm, (C2 a) measured aprox. 1 mm and the remaining (C2 b, A1 and A2) were larger than 1 mm. Sectioning of the blisters is necessary for a better dimensional characterization and for identification of cracks. This task will be undertaken once the samples are returned to Argentina, after completion of the ND tests by al the participating countries.

3.1.2 Eddy Currents

Inspection from the outside of PT:
In all cases, distinct EC blister signals were observed . They were however rather low, such that it took some time to find the experimental conditions for good measurements, because the indications are very close to the noise level. Thus the Z-plane indications (X-Y mode) were not clear-cut enough and better detection was achieved in the X-t; Y-t mode. The curves for the C2 blister is presented in Fig.3.

In the signals from the inspection of tubes A1 and A2, blister indications were just slightly above the signals produced by noise, lift-off and surface imperfections. This was not the case with the other tubes, and this difference may be due to the crazes and imperfections of the surface of these tubes in the blister zone, which hampered data acquisition.

Inspection from the inside of PT (opposite to the blisters):
No blister indications could be obtained.

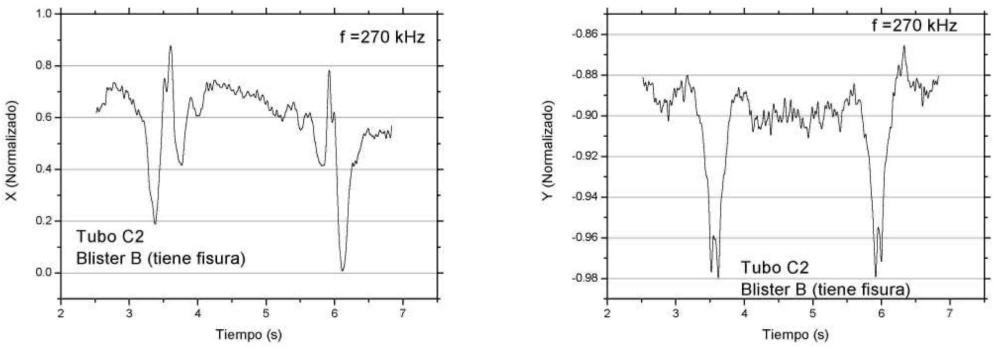
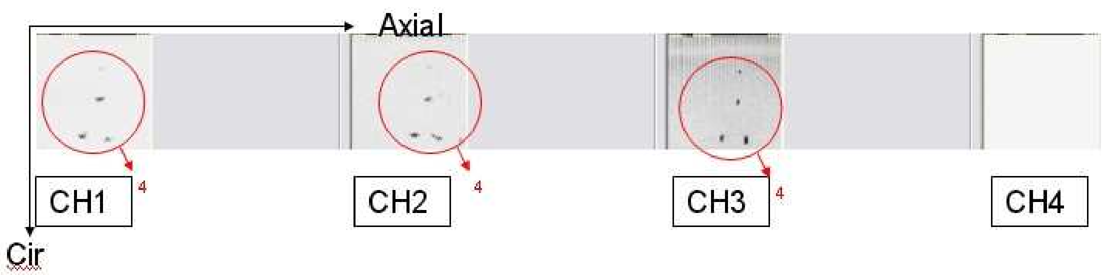


Fig .3. Eddy currents X(T) Y(t) signals for blister b in C2

3.2.3 Ultrasound

All six blisters were detected. C-scans for C2-***b*** blisters are shown (Fig 4) for comparison with the results from UT.



Gain CH1: 45 dB Gain CH2: 45 dB Gain CH3: 45 dB Gain CH4: Not working

Fig. 4. C-scans for blister b in C2

4. Conclusions

1) In the framework of an IAEA co-ordinated research Program an important effort was made to produce blisters on PT in order to assess the detection sensitivity of different ND techniques.
2) Blister detection was accomplished with UT from the inside of PT and with Eddy Current from the outside of PT.
3) Further work with EC is necessary for detection from the inside of the PT

References

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