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Preparation of Pressure Tube Creep Data using measurement and prediction

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1. Introduction

Due to unique design characteristic of CANDU reactor, pressure tube diametral expansion caused by irradiation and thermal creep is one of the major aging mechanisms of CANDU-6 reactor. Increasing of pressure tube diameter due to irradiation creep reduces the hydraulic resistance in the channel, hence increases flows, but causes the coolant to preferentially bypass the interior sub-channels of the bundle, reducing the ability of fuel cooling, thereby reducing Critical Channel Power (CCP).[1] To cope with this phenomenon, the prediction of diametral expansion of pressure tube is needed. Useful prediction can be derived from the accumulated measurement and prediction correlation.

2. Pressure tube creep

High internal pressure, irradiation and temperature cause circumferential and longitudinal expansion in geometry of pressure tube. The longitudinal expansion of pressure tube pushes the free end of tube to the end shield and can cause the rupture of bellows joined at end shield, finally the loss of coolant accidents.

Due to the weight of fuel channel and longitudinal expansion, pressure tube and Calandria tube sag downward to potentially contact the horizontal Liquid Injection Nozzle (LIN).

Increasing of pressure tube diameter causes the coolant to preferentially bypass the interior sub-channels of the bundle, reducing CCP. Only the diametral creep is related to thermal-hydraulic safety margin.

3. Pressure tube Inspection

The inspection apparatus measures inner diameter and thickness of pressure tube along the axis of channel, location of spacers, flaws in tube metal and length of tube. The inner diameter measurements of channels measured repeatedly are very useful data to correct the predicted creep rate. For Wolsong-1, pressure tubes were inspected in 1990, 1992, 1994, 2001 and 2004. 11, 17, 14, 9 and 12 channels were measured respectively. 41 channels were measured and 12 channels had been inspected repeatedly. Channel O14 and Q06 were measured four times. Channel C08, L09 and M11 were measured three times. E09, L06, Q07, Q08, Q11, S15 and U11 were measured twice. Pressure tube expands in the shape of oval. The mean value of the major axis and minor axis of maximum oval is used as maximum diameter.

The typical diameter profile along the axis of pressure tube is in the shape of cosine skewed to outlet end as shown in Figure 1.

4. Prediction of Creep

Creep strain is a function of neutron flux, pressure and temperature. Neutron flux shape changes in the form of cosine curve along the axis, but the temperature of coolant is getting higher along the axis. This made the diameter profile skew to the outlet side. Generally, the maximum diameter appears on the ninth or tenth bundle location. The eleven deeps in diameter profile are the locations of end plate of fuel bundle without neutron flux. Each end is rolled joint part with larger diameter.

Atomic Energy of Canada Limited (AECL), designers of CANDU-6, had developed pressure tube creep rate prediction program (RC-1980) on the basis of experimental data. Integrated fast neutron flux, coolant temperature and internal pressure of pressure tube are basic information for creep rate prediction. Prediction data for 6585EFPD, 7500EFPD, 8500EFPD and 9500EFPD were prepared to assess thermal-hydraulic margin in the future. Pressure tube diameter calculated with predicted creep rate is compared with that of the measured and appropriate correction with an uncertainty can be obtained.

5. Correction of Creep Prediction

At first, a correction for hot-state was done. Test facility used to produce RC-1980 correlation has diameter of 103.91 mm at cold-state and 104.11 mm at hot-state. Since initial diameter of channels were measured at cold-state and had different value from channel to channel, correction for diameter is needed to use RC-1980 prediction data as follows:

Correction factor for hot-state
= [(Initial dia./103.91)×(1+Creep rate×24×EFPD)-1]
/(Creep rate×24×EFPD).

The output of RC-1980 is in the shape of strain rate (i.e., strain/hr).

At second, a correction for measurement was done. Although pressure tube creep data for assessment of thermal-hydraulic margin should be based on real measurement, it is impossible to measure all the channels. So, prediction data based on experiments is used for unmeasured channels. Correction factors are obtained for every measured channel and average value of correction factors of measured channel is used for unmeasured channels. Correction factors are calculated for channels measured more than twice. Trend of diametral expansion can be obtained from the plot of diameter vs. irradiation for channels. Under the assumption of linearity of creep, initial diameter of channel can be derived from the trend line of each channel measured more than twice (see Figure 2). For channels measured just one time, initial diameter is corrected by the average difference between derived diameter and installation diameter of channels measured more than twice. With this corrected initial diameter and measured diameter, creep strain (in the unit of %) can be obtained. By dividing creep strain by irradiation (1000EFPD), strain per irradiation is calculated. For specific irradiation, the fraction of creep strain obtained by trend line of measurement over creep strain calculated by RC-1980 prediction is the correction factor for prediction. The average value of correction factors for measured channels is used as correction factor for unmeasured channels.

The final correction factor is the multiplication of two correction factors obtained above.[2]

6. Conclusion

Once RC1980 predictions are bias corrected the hydraulic model is in excellent agreement with the best-estimate measured data trend and its linear extrapolation as shown in Figure 3.

This corrected creep data will be used to calculate Critical Channel Power for assessment of thermal-hydraulic margin.

References

[1] W.J. Hartmann and M. Cormier, "Plant Aging Adjustments to Maintain Reactor Power at The Point Lepreau Generating Station", The 5th International Conference on CANDU Maintenance, 2000 Nov.

[2] Y.B. Kim et.al, "ROP Trip Setpoint Analysis Report For Wolsong Unit 1", KHNP, 2004 Nov.

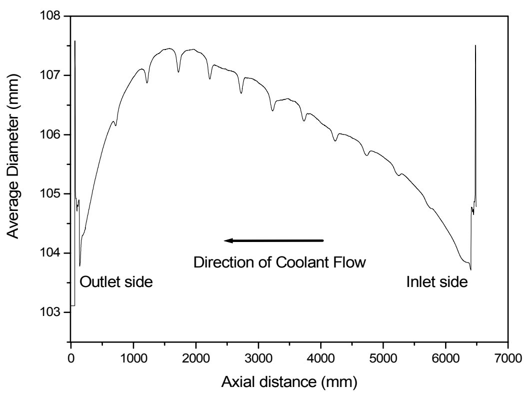

Figure 1 Profile of Pressure Tube Diameter

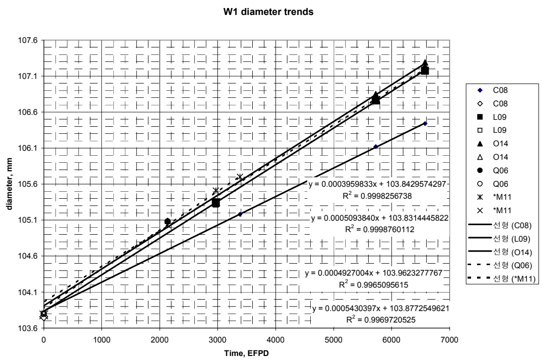

Figure 2 Trend of diametral Expansion

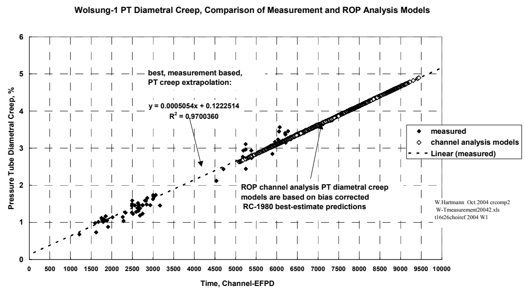

Figure 3 Comparison of corrected prediction and measurement