Critical Channel Power Reduction due to Pressure Tube Diametral Creep

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1. Introduction

Pressure tube diametral expansion due to irradiation and thermal creep is one of the major aging mechanisms of CANDU-6 reactor. The characteristic design concept of pressure tube causes this CANDU-6 unique phenomenon. 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] With the prediction of creep rate, the quantitative assessment of CCP reduction is performed.

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.

For Wolsong-1, pressure tubes were inspected in 1990, 1992, 1994, 2001 and 2004. In each year's inspection, more than 12 channels are measured and some channels had been inspected repeatedly. 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.

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. 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 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. Pressure tube diameter calculated with predicted creep rate is compared with that of the measured and appropriate correction with an uncertainty can be obtained.

3. CCP models for future EFPD

To find the tendency of CCP reduction due to pressure tube diametral creep, three different CCP analysis models of future EFPD had been generated. CCP of 6585 EFPD is the basis model and CCPs of future EFPD are compared with that of the basis model.

Three different creep rate data are produced for 7500, 8500 and 9500 EFPD. With the same boundary condition and different creep rate, prototype model of 6585 EFPD is modified to represent the flow redistribution due to larger diametral expansion in high power channels. The modification of model is done by changing the roughness of feeders and end fittings. Components above header remain unchanged. Irradiation and thermal creep effects on only fuel channel.

4. CCP calculations

CCP is calculated under the constant header-to-header differential condition with NUCIRC code. NUCIRC is a steady-state thermal-hydraulic code used by designers and analysts to examine the behavior of the HTS of a CANDU nuclear reactor over a wide range of single-phase and two-phase operating conditions.[2,3] NUCIRC can analyze CCP under the constant channel flow condition, too.

CCP analysis model based on June 16, 2004 (6585EFPD) is the basis model for future EFPD's model generation. For the boundary conditions such as temperature of reactor inlet header(T_{RIH}), pressure of reactor outlet header(P_{ROH}) and differential pressure between inlet and outlet header($\Delta P_{Header\text{-}to\text{-}Header}$), the same values as 6585 EFPD are used for future EFPD.

Nominal flux shape, nominal channel power distribution, is used to analyze CCP. CANDU-6 core can have over 800 cases of reactivity control device configurations. Each of those cases has different flux shape, namely, channel power distribution. Although, for analysis of Regional Overpower Protection (ROP), all the cases should be considered, the nominal case is sufficient to observe the effect of pressure tube creep on

CCP.

Channels E04 in peripheral region, L11 in center, O06 most limiting channel in accident analysis are selected to compare CCP reduction due to creep.

5. Results

Shown in Figure 2 is the predicted maximum diametral strain of each channel along the EFPD. It can be seen that strain increases linearly with EFPD. Channel L11 and O06 in high power region have steeper slope of strain than channel E04 in peripheral region. The more flux, the more creep. As creep increases, bypass flow increases around the fuel rod and decreases efficiency of cooling, finally the CCP reduces.

6. Conclusion

These quantitative assessments are based on the assumption of constant header boundary condition for the future EFPD. If there is change in boundary condition, absolute value of CCP will be shifted upward or downward, yet the tendency of CCP reduction will not change.

The reduction of CCP means the smaller margin to dryout. This has an effect on ROP trip setpoint. Due to pressure tube diametral creep, trip setpoint should be lowered as EFPD increases. It can be implemented as a penalty on setpoint.

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] D.J. Wallace, "NUCIRC Program Abstract and Theory Manual", TTR-765 Rev. 2, AECL, 2003 June.

[3] F. Huang, "NUCIRC User's Manual", TTR-422 Rev. 4, AECL, 2003 June.

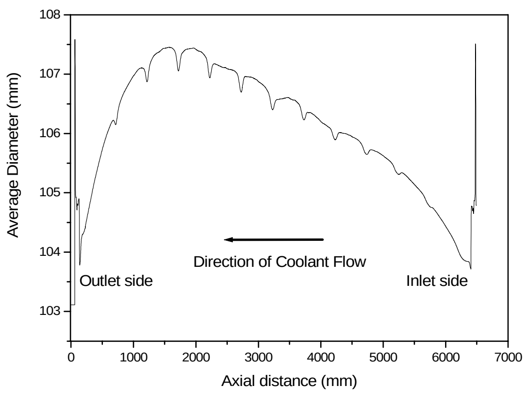

Figure 1 Diameter Profile

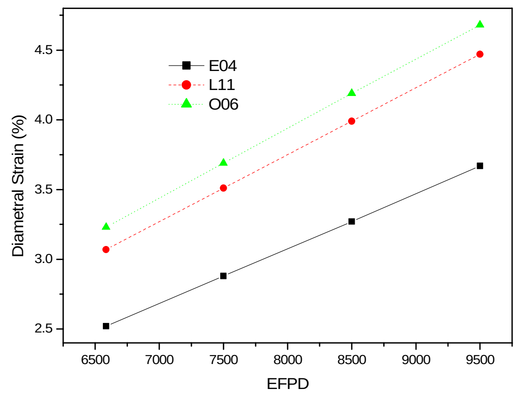

Figure 2 Diametral Strain

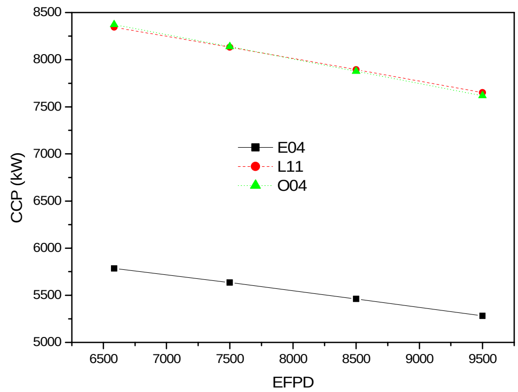

Figure 3 Tendency of CCP reduction