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Calculations of the Amount of the Change in Thermal and Elastic Expansion of Fuel Channels As the Reactor Ages

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I. Introduction

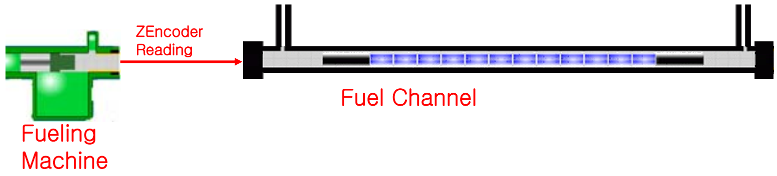
The design life of Wolsong Unit 1 is 30 years, and it has been operated for 23 years. Wolsong Unit 1 was designed by AECL(Atomic Energy Canada Limited) which also designed Pickering, Darlington, Bruce and Point Lepreau nuclear power plants. The pressure tubes of Pickering Unit 1,2 were replaced in 1985, and the pressure tubes of Pickering Unit 3 were replaced in 1989 and the pressure tubes of Pickering Unit 4 were replaced in 1991. New Brunswick electric power has decided to refurbish Point Lepreau nuclear power plant which has the same operation age as the Wolsong Unit 1. The refurbishment of Point Lepreau nuclear power plant includes replacement of fuel channels. Fuel Channel repalcement was determined based on the analysis that the fuel channel is estimated to reach its lifetime limit in the near future.[1] The critical value of limitation upon the elongation of the fuel channel can be affected by the amount of thermal and elastic deformation during reactor heat and cool down. In this study, the amount of the change in thermal and elastic deformation during reactor start up and cool down was calculated. And the calculated values have been compared to each other with the reactor ages. And it was discussed that whether these various calculation results of thermal and elastic expansion can affect the estimation results of lifetime calculations of fuel channels.

II. Fuel channel deformations

The ends of the fuel channel assemblies in CANDU 6 reactors are supported on bearings. Axial deformation of the fuel channel assembly is accommodated by movement of the end fittings over the bearings. A journal ring and bearing sleeve are engaged over a distance referred to as the bearing allowance. The minimum bearing allowance must be sufficient to accommodate the axial displacement of the journal ring relative to the bearing sleeve resulting from the following processes. [2]

- Thermal expansion of the pressure tube and end fittings;
- Elastic deformation of the pressure tube and end fittings due to internal pressure;
- Thermal expansion of the calandria assembly;
- Thermal expansion of the positioning assembly
- Thermal creep, irradiation creep, and irradiation growth of the pressure tube.

Z-encoder readings are taken each time that the fuelling machines visit a fuel channel assembly in a CANDU reactor as shown in Figure 1. Values of elongation calculated from the z-encoder readings can be analysed to determine relationships between elongation and operating time, and hence to estimate the operating time at which elongation may exceed the available bearing travel.



Among the five kinds of deformations, as I mentioned before, creep deformation and irradiation growth are irreversible, which means permanent change, while the other four kinds of deformations are reversible, which means the fuel channel can come back to its size if the pressure or thermal stress are removed. "Bearing allowance" means the criteria of the fuel channel life which is determined by reversible and irreversible amount of the fuel channel elongation deformation. Anyway, the total amount that the bearing can move over the bearing sleeve is the sum of reversible and irreversible amount of the fuel channel deformation. Therefore, it is important to check out the amount of reversible change caused by thermal stress and pressure stress as the reactor ages.

III. Calculations of thermal and eleastic deformatoin

Reversible dimensional change comes from elastic expansion of the material due to thermal and pressure loads.[3]

$$\Delta\lambda^{PT}_{thermal} = \alpha^{PT}\,\lambda^{PT}\,\Delta T^{PT}$$

where,

$\Delta\lambda^{PT}_{thermal}$ = the amount of pressure tube length change due to thermal stress

α^{PT} = thermal expansion coefficient of pressure tube

λ^{PT} = length of pressure tube

ΔT^{PT} = temperature change of pressure tube

Above equation represents the amount of pressure tube length change due to thermal stress from about 25 ℃ to about 300 ℃ when the reactor starts.

$$\Delta\lambda^{PT}_{pressure} = \frac{P R^{PT}_{i} \lambda^{PT}}{E^{PT} t^{PT}} (0.5 - \upsilon^{PT})$$

where,

$\Delta\lambda^{PT}_{pressure}$ = the amount of pressure tube length change due to pressure load

P = Pressure of the coolant

E^{PT} = Youn'g modulus of pressure tube material. (=elastic modulus)

R^{PT}_{i} = inner radius of the pressure tube

t^{PT} = thickness of the pressure tube

υ^{PT} = Poisson's modulus of thre pressure tube. (=lateral expansion ratio)

Above equation represents the amount of pressure tube length change due to pressure load from about 0 MPa to about 15 MPa when the reactor starts.

Every year, plat heat up and cool down repeats. When the plant heats up, the temperture goes up from about 25 ℃ to about 300 ℃, and the pressure goes up from about 0 MPa to about 15 MPa, and the channel length increases and when the plant cools down, the channel length decreases. It repeats almost every year. One thing that should be taken ito accont is that the amount of the length change when the plant cools down is not the the same as the amount of the length change when the plant heats up.

Table 1 shows calculated results of thermal deformation when the reactor heats up or cools down. And Table 2 shows calculated results of elastic deformation by pressure when the reactor heats up or cools down.

In this calculation, following six assumptions were used.

Initial Pressure Tube Length = 6210 mm
Initial Pressure Tube Inner Radius = 107.2 mm
Initial Pressure Tube Thickness = 4.05911 mm
Creep(Elongation) Rate = 5 mm/year
The Amount of Initial Thermal Expansion = 8.534 mm
The Amount of Initial Elastic Expansion = 2.108 mm

As shown in Table 1 & 2, it is clear that the amount of total change after 30 years of operation can be neglected when we consider the amount of total value of available creep length which is 153 mm.(=6 inches). The result of this study means that we can use single value of thermal expansion and elastic expansion regardless of reactor age.

IV. Conclusion

In this study, the amount of thermal and elastic deformation during reactor start up and cool down was calculated. And the calculated values have been compared to each other as the reactor ages. It has been turned out to be that the amount of total change after 30 years of operation is so small that we can neglect it and that we can use single value of thermal expansion and elastic expansion regardless of reactor age.

Table 1. Calculated Results of Thermal Deformation When the Reactor Heats up or Cools down.

Years	Reversible Delta L (mm)	Constant	Irreversible Length(mm)
0	8.534	0.0013742	6210
2	8.548	0.0013742	6220
4	8.561	0.0013742	6230
6	8.575	0.0013742	6240
8	8.589	0.0013742	6250
10	8.603	0.0013742	6260
12	8.616	0.0013742	6270
14	8.630	0.0013742	6280
16	8.644	0.0013742	6290
18	8.658	0.0013742	6300
20	8.671	0.0013742	6310
22	8.685	0.0013742	6320
24	8.699	0.0013742	6330
26	8.713	0.0013742	6340
28	8.726	0.0013742	6350
30	8.740	0.0013742	6360
	0.206 = total change		

Table 2. Calculated Results of Elastic Deformation by Pressure of the Reactor Coolant

Years	Reversible Delta L (mm)	Constant	Inner radius (mm)	Thckness (mm)	Irreversible Length(mm)
0	2.108	1.29E-05	107.200	4.05911	6210
2	2.123	1.29E-05	107.414	4.04405	6220
4	2.139	1.29E-05	107.629	4.02908	6230
6	2.155	1.29E-05	107.843	4.01419	6240
8	2.170	1.29E-05	108.058	3.99938	6250
10	2.186	1.29E-05	108.272	3.98466	6260
12	2.202	1.29E-05	108.486	3.97003	6270
14	2.218	1.29E-05	108.701	3.95547	6280
16	2.234	1.29E-05	108.915	3.94100	6290
18	2.251	1.29E-05	109.130	3.92661	6300
20	2.267	1.29E-05	109.344	3.91230	6310
22	2.283	1.29E-05	109.558	3.89807	6320
24	2.300	1.29E-05	109.773	3.88391	6330
26	2.316	1.29E-05	109.987	3.86984	6340
28	2.333	1.29E-05	110.202	3.85585	6350
30	2.349	1.29E-05	110.416	3.84193	6360
	0.241 = total change				

REFERENCES

[1] KEPRI, "Wolsong Unit 1 Plant Lifetime Management Study (I), 2003.

[2] J.W.Bowden, Assessment of Fuel Channel Elongation and Bearing Availability, 2005

[3] J.W.Bowden, Technical Basis for Values of Bearing Allowance, 2005