Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Calandria Tube Sagging Prediction of Operating CANDU Reactor Fuel Channels

Young-Jin Oh [a*], Kyung-Su Kim [a], Heung-Bae Park [a], Sung-Nam Choi [b]
[a]*Power Eng. Research Institute, KEPCO-E&C, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, Korea*
[b]*Central Research Institute, KHNP, 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, 34101, Korea*
[*]*Corresponding author: yjoh2@kepco-enc.com*

1. Introduction

A CANDU type nuclear reactor is composed of a calandria vessel, fuel channels and vertical or horizontal tubes. Pressure tubes and calandria tubes are parts of fuel channels, which are pressure boundaries of primary heat transport system and moderator system, respectively. Because the fuel channel is located horizontally, the pressure tubes and calandria tubes are sagged by vertical dead weight loads and irradiation creep deformations during operation.

Due to the sagging of fuel channel, the calandria tube can be contacted with reactor internal horizontal tubes as shown in Fig. 1. Because this contact was not considered in the design stage, it is not allowed during reactor operation.[1] In this study, calandria tube sagging predictions are conducted using material irradiation creep equations and mechanical model of fuel channel of CANDU reactor, considering in-service inspection results of pressure tube sagging.

2. Numerical Model Summary

The basic calculation frame of this analysis is same as that of early research results about fuel channel sag deformation[2,3,4], as follows.

$$\frac{d^2Y_p(x,t_n)}{dx^2} = M_p(x,t_n)BIP(x,t_n) + \sum_{t=t_1}^{t_{n-1}} M_p(x,t)\Delta C_p(x,t)$$
$$\frac{d^2Y_c(x,t_n)}{dx^2} = M_c(x,t_n)BIC(x,t_n) + \sum_{t=t_1}^{t_{n-1}} M_c(x,t)\Delta C_c(x,t)$$
$$\Delta C_p(x,t) = \dot{C}_p(x,t)\Delta t / I_p$$
$$\Delta C_c(x,t) = \dot{C}_c(x,t)\Delta t / I_c$$
$$BIP(x,t) = 1/E_pI_p + \Delta C_p(x,t)$$
$$BIC(x,t) = 1/E_cI_c + \Delta C_c(x,t)$$

Where Y, M, $\dot{C}$, x, t, E and I are vertical displacement, section moment, irradiation creep coefficient, axial position, operation time, elastic modulus and moment of inertia, respectively. Subscript "p" and "c" means pressure tube and calandria tube, respectively. The irradiation creep coefficients are defined as follows, in which following creep coefficients were used according to previous research results[3,4].

$$\dot{\varepsilon}_b = \dot{C}\sigma_b$$
$$\dot{C}_p(x,t) = \left[3\times10^{-4}t^{-\frac{2}{3}} + 6\times10^{-23}\phi(x)\right]e^{\frac{-4700}{T(x)}} \quad \text{[/h/MPa]}$$

$$\dot{C}_c(x,t) = 1.16\times10^{-27}\phi(x) \quad \text{[/h/MPa]}$$

Where $\dot{\varepsilon}_b$ is creep bending strain rate, σ_b is bending stress, t is time [hour], ϕ is fast neutron fluence (>1MeV) [n/m^2/sec] and T is temperature [K].

In this calculation, nonlinear behaviors of gap between pressure tube and calandria tube were considered. Additionally, creep coefficients were adjusted to minimize the prediction difference from the measured results of pressure tube sag inspection.

3. Results and Conclusions

By solving the equations iteratively, Sagging predictions were evaluated for all related channels of a Wolsong CANDU unit. Fig. 2 shows an example of sagging prediction results. The prediction results of pressure tube sagging are shown to agree well with the measurement results.

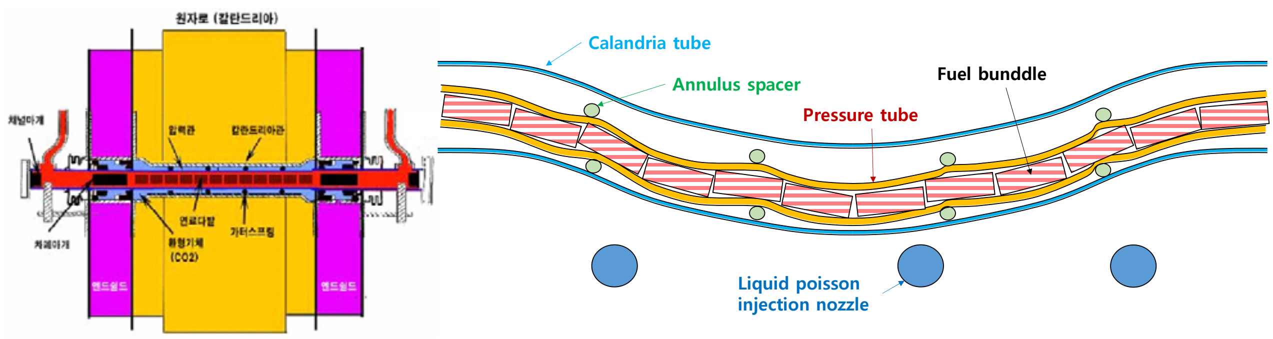

Fig. 1 CANDU fuel channel sagging deformation

This calculation method using mechanistic solutions and measurement results can increase the reliability of sagging prediction and help construct detail plan for aging management of CANDU fuel channels.

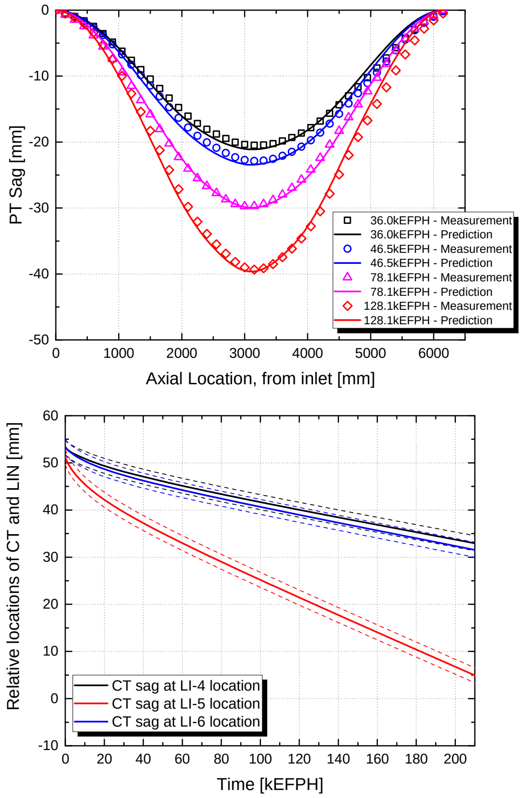

Fig. 2. An example of sagging prediction results

REFERENCES

[1] Canadian Standards Association, CAN/CSA N285.4-94, "Periodic inspection of CANDU nuclear power plant components", 1994.
[2] Pettigrew, M.J., Lambert, S.B., “Creep deflection analysis of fuel channels in CANDU nuclear reactors”, Transctions of the 5th international conference on SMiRT, Berlin.
[3] Tae Ryong Kim, Seok Man Sohn, “Computation and measurement of calandria tube sag in pressurized heavy water reactor”, Nuclear engineering and design, V.230, pp.339-348, 2004.
[4] Young-Jin Oh, et. al., Final report for “Development of mechanical analysis technologies for material reliability of major nuclear components”, KEPCO E&C, 2011.