Preliminary Evaluation on PCI Risk monitoring Module

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1. Introduction

There is currently significant growth in generation from renewable energy sources, because of strategies to reduce carbon emissions in order to meet government policies. There is, therefore, an increasing need to transition an existing nuclear power plant from baseload operation to flexible power operations (FPO). However, FPO involves subjecting the fuel to complex time-varying power histories that could increase the duty on the fuel rods and potentially challenge their integrity, especially by pellet cladding interaction (PCI)[1].

Finite element analysis is generally used to assess PCI risk due to local stress analysis and it takes long time. In addition, PCI risk is affected by time-varying power histories, it is necessary to evaluate many rod cases. Therefore, rapid PCI risk evaluation methodology is developed in a previous study[2]. That methodology is further improved and used for preliminary evaluation on PCI Risk monitoring. Results are described herein.

2. Methods and Results

2.1 Hoop Stress Assessment Methodology

In previous study[2], hoop stress was obtained using power to zero stress (called, PZS) and constant stress to power ratio which does not reflect the tendency of stress increase due to thermal conductivity degradation. The accuracy of stress prediction was improved using stress to power curve according to local burnup and power instead of constant stress to power ratio.

The hoop stress assessment methodology can be used regardless of code type such as ROPER, ABAQUS, because this methodology used code results such as stress to power curve.

2.2 Comparison with ROPER

Fig. 1 shows the results of comparing predicted hoop stress and ROPER calculation at start-up condition for APR1400 plant. The accuracy of stress prediction was improved compared to previous result (Fig. 4[3]).

Fig. 2 and Fig. 3 show the results of comparing predicted hoop stress and ROPER calculation. The calculation condition in Fig. 2 and Fig. 3 are xenon oscillation during baseload operation and load-following operation for APR1400 plant, respectively. Fig. 4, Fig 5 and Fig 6 shows hoop stress and power vs. time of maximum stress case. PCI limit in Fig. 4, Fig 5 and Fig 6 means the power at which the hoop stress reaches the hoop stress limit. The hoop stress limit was determined from results of ramp test evaluation.

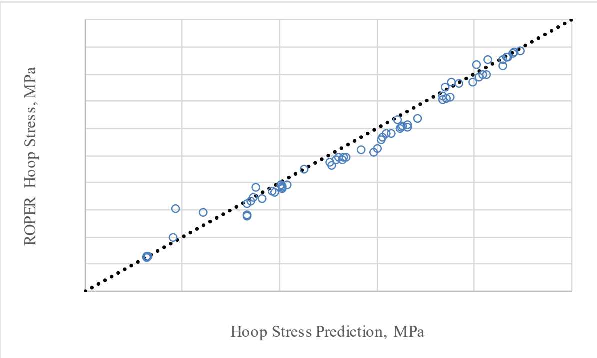

Fig. 1. Hoop stress comparison at start-up condition.

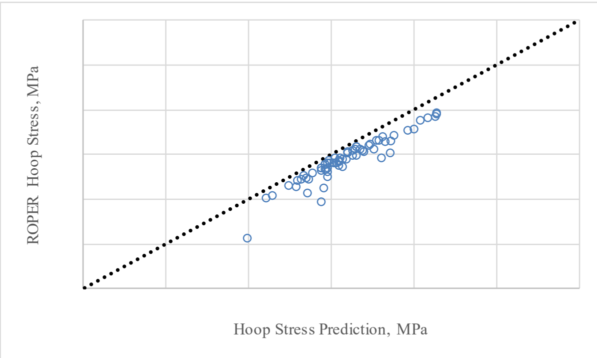

Fig. 2. Hoop stress comparison at xenon oscillation condition during baseload operation.

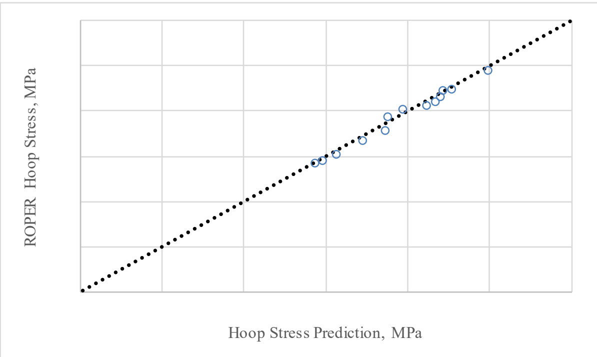

Fig. 3. Hoop stress comparison at xenon oscillation during load-following operation.

The hoop stress prediction results agree well with the results of ROPER code calculation including load-following operation. But predicted stress is slightly high in Fig. 2. This is because the hoop stress assessment methodology evaluate pellet to cladding contact faster than ROPER. The hoop stress of prediction in Fig. 4, Fig. 5, Fig. 6 increase faster than ROPER.

The power increase of all case in Fig.1 and 3 occurs at end-of-cycle pellet-clad gap condition. Generally, there is equilibrium between the cladding stress relaxation due to creep and the outward expansion due to swelling at end-of-cycle. But the power increase of case in Fig.2 occurs over the entire cycle. That is the reason for the over prediction in Fig. 2.

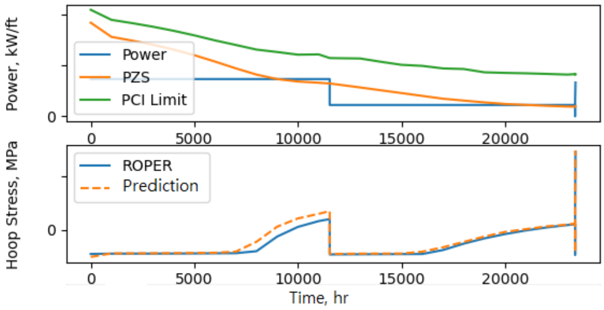

Fig. 4. Hoop stress vs. time at start-up condition.

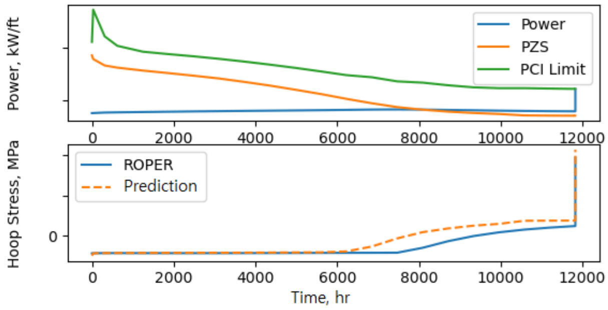

Fig. 5. Hoop stress vs. time at xenon oscillation condition during baseload operation.

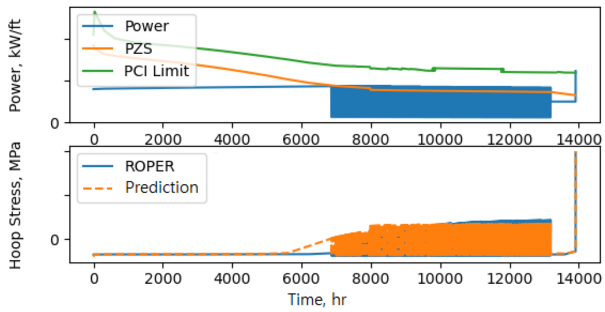

Fig. 6. Hoop stress vs. time at xenon oscillation during load-following operation.

2.3 Preliminary evaluation on PCI Risk

Preliminary evaluation on PCI Risk was performed using hoop stress assessment methodology and python program as follow.

- Sends nuclear power data of quarter core to PCI risk monitoring module periodically.
- Hoop stress and power limit were calculated using hoop stress assessment methodology. Initial pellet-clad gap condition for each rod was assumed using PZS distribution according to burnup and depletion power calculated by ROPER code.
- Check the PCI margin of limited fuel rod.

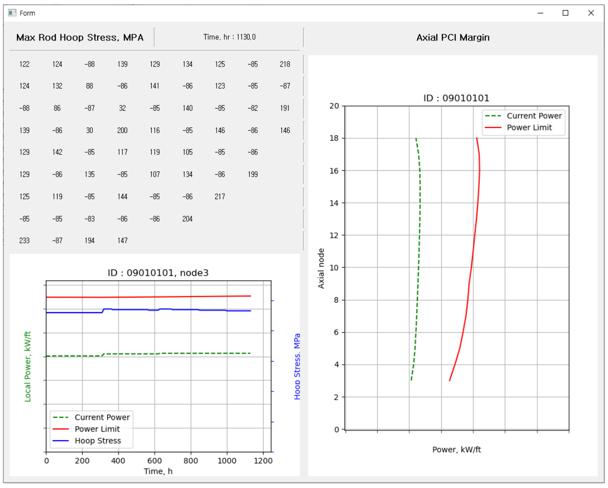

Fig. 7. Preliminary PCI risk evaluation result.

3. Conclusions

Hoop stress assessment methodology which is developed previous study was improved. It was confirmed that the calculated hoop stress at each axial position of the whole core by the PCI risk monitoring module well simulates the evaluation results of the fuel rod design code. This module can be a useful tool in that it can evaluate the stress of all fuel rods in short time than fuel rod design code. But the current module still doesn't calculate fast enough and does not take into account uncertainty. In the future, we plan to reduce calculation time in tens of seconds and take into account the geometry, model and calculation uncertainty to the hoop stress.

REFERENCES

[1] S. Yagnik, An Assessment of Fuel Performance Requirements for Baseload Nuclear Power Plants Transitioning to Flexible Power Operations, 3002009087, EPRI, October 2016.

[2] Hak-Kyu Yoon, et al., Development of Rapid PCI Risk Evaluation Methodology based on Hoop Stress Assessment, Transactions of the Korean Nuclear Society Autumn Meeting Changwon, Korea, October 21-22, 2021