THE APPLICATION OF ADJOINT TRANSPORT CALCULATIONS TO EX-CORE DETECTOR CALIBRATION

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ABSTRACT

Ex-core detectors at the core periphery are regularly calibrated to correctly measure core power axial offset during operation. A conventional method for ex-core detector calibration requires use of in-core detectors to measure core power distribution several times. It employs the least square method to obtain proportional constants used for ex-core detector calibration. Simplified Ex-core Detector Calibration (SEDC) presented here requires only a core power distribution measurement. It combines three-dimensional power distribution calculated from a nodal calculation and weighting factors calculated from (r-z) and (r-θ) adjoint transport calculations to generate detector response factors. The detector response factors involves effects of assembly-wise importance of neutron as well as core axial importance of neutron to a ex-core detector. The effects of core burnup, coolant temperature and core power on the accuracy of the SEDC are also explored using Kori unit 3 data. The application of the SEDC to Kori unit 3 cycle 9, 10 and 11 shows average error of 0.179% and maximum error of 0.629%.

1. INTRODUCTION

Ex-core detectors symmetrically located at core periphery provide reactor protection against rapid power rate change, core overpower and axial power maldistribution and require periodic calibration during operation. The ex-core detector calibration method currently employed for Kori unit 3 is a multi-point calibration method which requires several full core power measurements using in-core detectors. The multi-point calibration method employs the least square method which linearizes a relationship between axial offset of the in-core detectors and ex-core detector current. The Simplified Ex-core Detector Calibration (SEDC)[1] linearizes the relationship by introducing Detector Response Factors (DRFs) which convert ex-core detector current to core power. A DRF is calculated from three-dimensional power distribution, axial weighting factor and assembly-wise weighting factor. The axial weighting factor and the assembly-wise weighting factor are computed from (r-z) adjoint transport calculation and (r-θ) adjoint transport calculation, respectively. Three-dimensional power distribution is calculated from a nodal diffusion calculation. The synthesis of the axial weighting factor and the assembly-wise weighting factor approximates three-dimensional distribution of spatial weighting for a ex-core detector. The weighting factors calculated from a transport code simply weights contribution of core power to a ex-core detector, which changes during core burnup. Kori unit 3 cycle 9, 10 and 11 data are used for the verification of the SEDC.

2. DETECTOR RESPONSE FACTOR CALCULATION

The DRF described in the reference 1 used only core axial weighting factors obtained from (r-z) adjoint transport calculation by DORT[2]. The axial weighting factor calculation assumed homogeneous core so that assembly-wise weighting factor distribution in a core was neglected. This is not real situation because an assembly at the core periphery close to a ex-core detector has bigger assembly-wise weighting factor than one in the inner core. Therefore, assembly-wise weighting factor is required for the SEDC to consider assembly-wise importance of neutron to ex-core detector. the two-dimensional (r-θ) adjoint transport model used for assembly-wise weighting factor calculation assumes homogeneous quarter core and has 255 meshes in r-direction, 240 meshes in the θ -direction with reflective boundary condition. The cross-section library used for adjoint transport calculation is BUGLE-93[3] which has 47 neutron energy group. The assembly-wise weighting factors for Kori unit 3 cycle 10 at BOL HFP are shown in Figure 1.

0.0	0.0	0.0	0.0	0.0	0.0003	0.0024	0.0234
0.0	0.0	0.0	0.0	0.0002	0.0012	0.0088	0.0857
0.0	0.0	0.0001	0.0002	0.0009	0.0056	0.0390	
0.0	0.0	0.0002	0.0018	0.0056	0.0195	0.1276	
0.0	0.0002	0.0009	0.0056	0.0424	0.1574		
0.0003	0.0012	0.0056	0.0195	0.1574			
0.0024	0.0088	0.0390	0.1276				
0.0234	0.0857						

Figure 1. Assembly-wise weighting factor for Kori unit 3 cycle 10 at BOL, HFP

Assuming weighting factors are separable in a core, the DRF can be written as:

$$R_j^k = \frac{\sum_{j=1}^{N} P_j(r) w_j(r) \sum_{i,k\in T,B} P_{j,k}(z) w^i_{j,k}(z)}{\sum_{j=1}^{N} P_{j,}(r) \sum_{k\in T,B} P_{j,k}(z)} \qquad (1)$$

T and B in the equation (1) denote upper region of a core and lower region of a core, respectively. $w_j(r)$ and $w^i_{j,k}(z)$ denote assembly-wise weighting factor and core axial weighting factor, respectively. Core power in the right-hand side of the equation (1) is calculated from three-dimensional nodal code ANC[4]. Using the DRFs determined prior to a core power measurement, an ex-core detector response matrix equation is obtained:

$$C_{2x1} = \mathbf{R}_{2xm}\mathbf{P}_{mx1} \qquad (2)$$

C_{2x1}, $\mathbf{R}_{2xm}$ and $\mathbf{P}_{mx1}$ are a detector current vector, a detector response matrix and a core power vector, respectively. The subscript m is number of axial core mesh. Since the transport calculational model used for the DRF in the equation (1) assumes ARO (All Rod Out) and the magnitude of the DRF changes with control rods movement, a bias factor is multiplied to the DRF. The bias factor which correct the DRF change due to control rods movement is obtained from the ratio of ex-core detector current to predicted ex-core detector response. With help of simple mathematics, equation (2) can be rewritten to get the proportional constants required for ex-core detector calibration.

3. RESULTS

The accuracy of the SEDC depends on how to determine the DRF. The DRF depends on various parameters such as core burnup distribution, coolant temperature distribution and core power rate. To explore the effect of those factors, Kori unit 3 cycle 9~11 data are applied to the SEDC.

3.1 Axial Coolant Temperature Distribution

The neutron attenuation effect due to coolant temperature change in bypass region is not negligible. Axial weighting factors for Kori unit 3 cycle 10 at BOL were calculated from (r-z) adjoint transport calculation considering axial coolant temperature distribution. Figure 2 shows that axial weighting factor increases as coolant temperature increases, compared with flat coolant temperature distribution. These results suggest that coolant temperature effect to the axial weighting factor is important to the DRF calculation. In this comparison calculation, the same power distribution was used for DRFs calculation. However, the result of the SEDC with coolant temperature effect is almost same as that without coolant temperature effect for Kori unit 3 cycle 10.

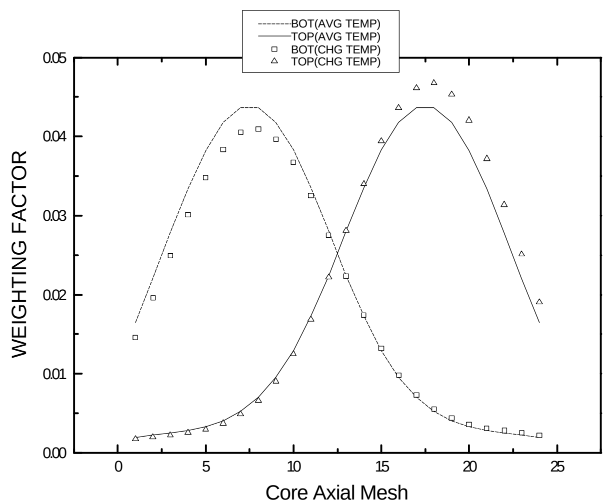

Figure 2. Axial weighting factor distribution

3.2 Axial Burnup Distribution

Burnup distributions of BOL and EOL of Kori unit 3 cycle 10 were used for (r-z) adjoint transport calculation. Although the two cases have different burnup distribution, (r-z) adjoint transport calculation shows that axial weighting factor distributions for the two cases are almost identical. It suggests that axial weighting factor distribution is almost independent of core burnup distribution, which means the SEDC is insensitive to core burnup distribution. The axial core power distributions applied to DRFs generation are different and the SEDC with the EOL power distribution shows better result than that with the BOL power distribution, reducing the average error of 0.342% to 0.223%.

3.3 Core Power rate

Change of core power rate results in change of core coolant temperature distribution as well as core power distribution. Axial weighting factor distributions for both 75% power and 100% power were calculated at BOL of Kori unit 3 cycle 11. Figure 3 shows that core power reduction from 100% to 75% slightly reduces the axial weighting factor distribution in upper core region, which is due to coolant temperature decrease in upper core region. When the DRFs calculated from 100% power were applied to ex-core detector current measured at 75% power of Kori unit 3 cycle 11, the SEDC shows an average error of 0.266%. However, the SEDC with DRFs calculated from 75% power shows improved result which is an average error of 0.179%.

3.4 Core Radial Power Distribution

The above results suggest that the accuracy of the SEDC is more dependent on predicted power distribution rather than weighting factor distribution. The predicted power distribution is dependent on core burnup step. Therefore, core power distributions are calculated at various burnup steps while weighting factor distribution is assumed constant during core depletion. The SEDC was applied to Kori unit 3 cycle 9,10 and 11, considering various power distributions. Figure 3 shows calibration error distribution of the SEDC. The SEDC with core radial power distribution improved results which are maximum error of 0.624% and average error of 0.179%. But the SEDC without core radial power distribution shows maximum error of 0.651% and average error of 0.212%.

4. CONCLUSION

The objective of the study is to replace the multi-point method with the SEDC and to minimize calibration time. For this purpose, detector response factors are calculated prior to a flux measurement. The study shows that the detector response factors are sensitive to axial core coolant temperature distribution, core power rate. The SEDC were applied to Kori unit 3 cycle 9,10 and 11, considering coolant temperature, core burnup step and the effect of radial power distribution to ex-core detector. The SEDC with assembly-wise weighting factor reduced the average error from 0.212% to 0.179% and maximum error from 0.651% to 0.624%, compared with the SEDC without assembly-wise weighting factor. The SEDC also showed comparable accuracy to the multi-point method after ex-core detector calibration.

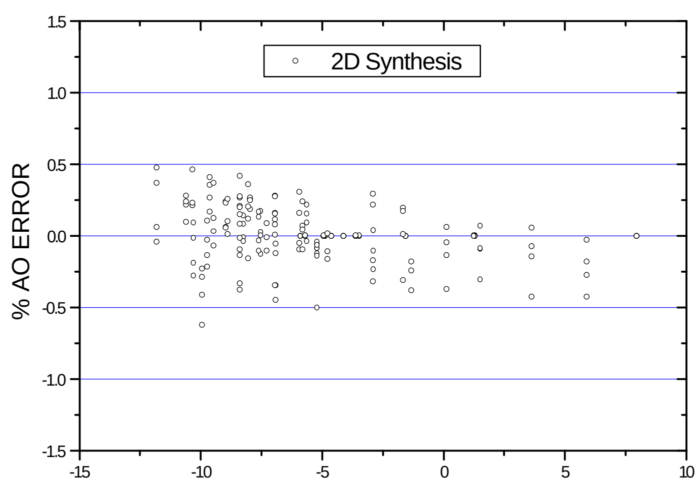

Figure 3. Calibration Error Distribution for Kori unit 3 cycle 9~11

5. REFERENCES

1. C.J. Hah. "Simplified Ex-core Detector calibration":*International Conference on the Physics of Reactors PHYSOR96*, vol. 2, pp k-60, Mito, Japan, 1996.
2. W. A. Rhoades and R. L. Childs. "The DORT Two-Dimensional Discrete Ordinates Transort Code," *Nucl. Sci. Eng.*, vol. **99**, pp 88, 1988.
3. D.T. Ingersoll. *Production and Testing of the VITAMIN-B6 Fine-Group and the BUGLE-93 Broad-Group Neutron/Photon Cross-Section Libraries Derived from ENDF/B-VI Nuclear Data,* ORNL-6795, 1994.
4. Y. S. Liu. *ANC: A Westinghouse Advanced Nodal Computer Code*, WCAP-10965, Westinghouse.