Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Evaluation of power distribution synthesis feasibility for hybrid in-core detector for i-SMR

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**keywords : power synthesis, PCF, i-SMR, hybrid in-core detector, axial power distribution*

1. Introduction

The currently under-development i-SMR (Innovative Small Modular Reactor) will employ a hybrid in-core detector utilizing both cobalt and rhodium emitters. The addition of cobalt emitters is intended for application in the core protection system using prompt signals from cobalt's (n,r,e) reactions. To overcome the lower reaction rate of cobalt emitters, their diameter and length will be larger compared to those of rhodium emitters. While five rhodium emitters are typically loaded, cobalt emitters are loaded axially with three units to avoid overlap as their lengths increase. Consequently, it is essential to verify whether axial power distribution synthesis can be effectively achieved with the altered number of axial emitters. This paper evaluates the feasibility of synthesizing axial power distributions for hybrid in-core detector intended for the i-SMR by generating signals from three axial simulated signal in an OPR1000 reactor and comparing them to those obtained using traditional Fourier fitting and the DPCM3D method [1].

2. Methods and Results

2.1 Determination of Emitter Axial Position

In commercial reactors, the axial power distribution typically exhibits a cosine shape but evolves into a saddle shape towards the end of the cycle. Therefore, the number and position of emitters are determined to accurately simulate the axial power distribution throughout the entire burnup cycle. For OPR1000 and APR1400 cores, the number and placement of axial emitters in the in-core detector are depicted in Fig 1. In contrast, the i-SMR under development will utilize a hybrid in-core detector (Fig 1.) incorporating three cobalt emitters intended for core protection purposes. Due to cobalt emitter lower reaction rate compared to rhodium, the diameter and length of the cobalt emitters have been increased. Additionally, careful selection of emitter center positions was made to prevent overlapping of axial cobalt emitters.

2.2 Production of simulated measurement signals

To assess whether accurate axial power distributions can be produced using signals from cobalt emitters in the hybrid in-core detector, simulated measurement signals for the cobalt emitters were generated. For precise calculations, the in-core detector must be accurately modeled. However, since the focus of this paper is on evaluating the accuracy of axial power distribution syhthesis with varying emitter lengths and positions, simulated signals (I) corresponding to the axial fuel node power of emitter lengths were derived without detailed in-core detector modeling, as shown in Equation (1).

$$P = \frac{I}{S} \times W' \times CALIB \qquad (1)$$

Where, P = node power
I = signal of detector
S = sensitivity of detector
W'= signal to power constant
CALIB = calibration factor

Using Equation (1), node power can be calculated with the 3D core simulation code. By assigning arbitrary values to all constants except for detector signal I, the simulated signal can be obtained. It should be noted that all constants, except for I, will be maintained unchanged throughout the power distribution synthesis process.

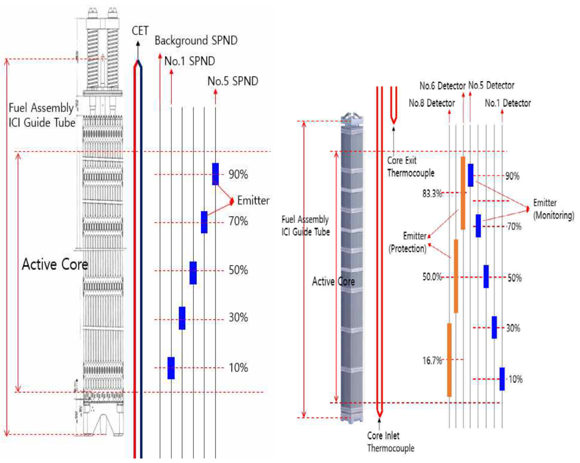


Fig. 1. Emitters axial position for OPR1000/APR1400(left) and i-SMR(right)

2.3 Simulation of measured power distribution

The simulated measurement power distributions were produced using the ASTRA code [2]. The target core was an OPR1000 core, and axial power distributions for specific fuel assembly were produced at BOC and EOC, as illustrated in Fig 2.

2.4 Axial power distribution synthesis

For axial power distribution synthesis, both the traditional Fourier fitting method used in commercial reactor designs and the DPCM3D fitting method were employed for comparison. The DPCM3D method, developed by KAERI, is incorporated into KEPCO NF's AsCORE code. Fig. 3 presents the results of Fourier fitting and AsCORE code axial power distribution calculations based on simulated measurement power distributions (ASTRA) and simulated measurement signals.

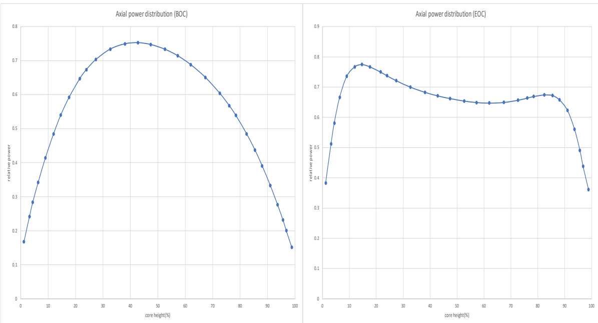
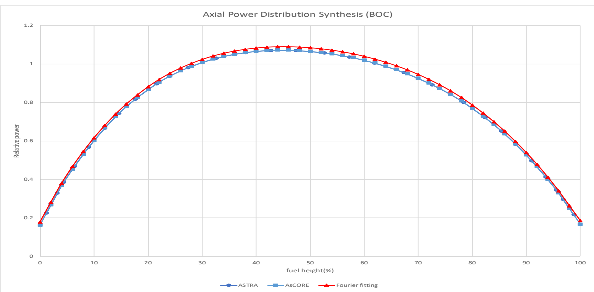
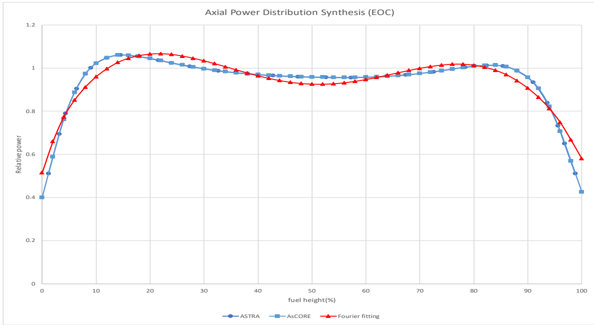


Fig. 2. Axial power distribution at BOC(left) and EOC(right)

Fourier fitting of the axial power distribution based on five emitters has been shown to accurately predict the saddle shape of the EOC to a certain extent. However, with only three emitters, as demonstrated in Fig. 3, the saddle shape prediction becomes less accurate. This discrepancy increase uncertainty in power distribution synthesis, thereby reducing the operational margin of the core. In contrast, AsCORE effectively predicts the axial power distribution even with three emitters. Theoretically, AsCORE's synthesis uncertainty is 0%. Therefore, as shown in Fig. 3, the power distribution synthesized using AsCORE with the simulated signal matches the power distribution of ASTRA.





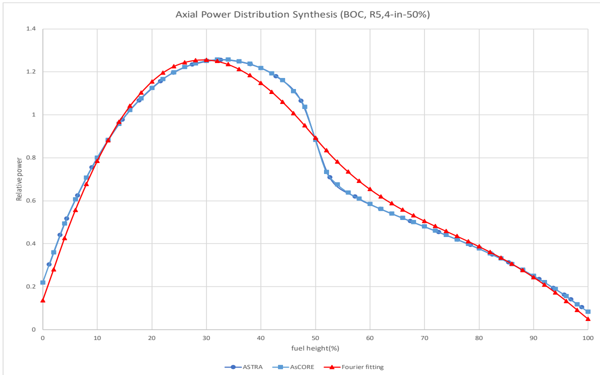


Fig. 3. power synthesis result at BOC(upper), EOC(center) and R5,4 50% insertion at BOC(lower)

3. Conclusions

The feasibility of synthesizing axial power distributions based on cobalt emitter signals from hybrid in-core detector for iSMR was evaluated. It was found that the Fourier fitting method, previously used for rhodium-based in-core detector, was no longer applicable due to changes in emitter length and positioning. In contrast, the AsCORE code from KEPCO NF is evaluated to accurately predict the measured power distribution based on cobalt emitter signals for iSMR applications.

4. Acknowledgements

This work was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korea Government (RS-2023-00265742).

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