Performance Improvement of the Core Protection Calculator System (CPCS) by Introducing Optimal Function Sets

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1. Introduction

The Core Protection Calculator System (CPCS) is an automated device which is adopted to inspect the safety parameters such as Departure from Nuclear Boiling Ratio (DNBR) and Local Power Density (LPD) during normal operation. One function of the CPCS is to predict the axial power distributions using function sets in cubic spline method. Another function of that is to impose penalty when the estimated distribution by the spline method disagrees with embedded data in CPCS (i.e., over 8%). In conventional CPCS, restricted function sets are used to synthesize axial power shape, whereby it occasionally can draw a disagreement between synthesized data and the embedded data. For this reason, the study on improvement for power distributions synthesis in CPCS has been conducted in many countries.

In this study, many function sets (more than 18,000 types) differing from the conventional ones were evaluated in each power shape. Matlab code was used for calculating/arranging the numerous cases of function sets. Their synthesis performance was also evaluated through error between conventional data [1] and consequences calculated by new function sets.

2. Methods and Materials

Axial power distribution is synthesized by summing the multiplied values between cubic spline basis functions and amplitude coefficients as shown in Eq. (1) [2].

$$P(z) = \sum_{i=1}^{7} a_i \mu_i(z) \qquad (1)$$

where, $P(z)$ = Axial Power Disribution at Location z
a_i = Amplitude Coefficients
$\mu_i(z)$ = Cubic Spline Basis Functions

To predict the axial power distribution, it is required to calculate amplitude coefficients by the signals from ex-core detectors in Eq. (2). The signals are transformed to partial reactor power (upper, middle, and lower) by SAM related to B_j. In Eq. (2), H is a 7 by 7 matrix, namely spline matrix, which consists of integral values of cubic spline basis functions in the range of three predetermined region as shown in **Figure 1**. Additionally, boundary point power and boundary values of basis functions are essential components for B_j and H matrix respectively.

$$a_i = \sum_{j=1}^{7} B_j \cdot H^{-1} \text{ (i=1,2,3,...,7)} \qquad (2)$$

Spline matrix, H in Eq (2), has only a dominant effect to synthesize axial power shape because the values related to B_j are not varying in CPCS. The ruling effect of H is also depends on cubic spline function sets. That is, cubic spline function set determines that each interval (A, B, C, D) are assigned to axial core height as shown in **Figure 1**, and basis functions are located according to the intervals. Therefore, the integral values of basis function in spline matrix are changed.

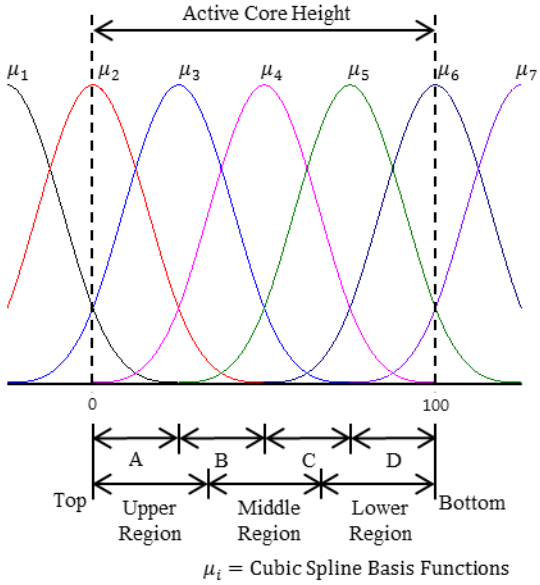

Figure 1. Schematic of Cubic Spline Method

In conventional study, axial core height is divided into twenty nodes and each node is assigned to the intervals. For example, 2 8 8 2 function set distributes 2, 8, 8, 2 nodes into A, B, C, D intervals sequentially. Moreover, the function sets have a symmetric condition that the number of assigned nodes into A and B interval should be equal to the number of nodes assigned into C and D interval because there are so many cases to be considered without the condition. However, the results calculated by the function sets are not occasionally satisfied with reference data, especially in an asymmetric shape. In this study, various function sets including symmetric and asymmetric condition were chosen to improve the drawbacks. There are 18,424 types of function sets considering all possible cases to assign 50 nodes into 4 intervals. To evaluate performance obtained by using the function sets, Root Mean Square (RMS) error, the difference between synthesized power distribution and reference data, was analyzed in each function set. And then, optimal and improved function sets were determined to be suitable for predicting axial power distribution. This study was performed by using reference data [1] presenting many axial power distribution and axial burn up data.

3. Results and Discussions

From the analysis of many cases, it was found that RMS error extended over wide range from 0.3 % to 450 %. Application of the optimal function sets established in this study can also decreases RMS error by 27.18% in comparison with conventional ones. **Figure 2** shows that the results obtained by optimal ones agreed well with the reference data as compared with previous ones. The results also show that asymmetric function sets were used as optimal ones in 73.75% of all reference data. It means that the symmetry condition should be improved because the prevalent function sets are not reliable for expecting power shapes in some cases. Accordingly, two function sets to be good for synthesizing power distributions were selected in accordance with shape classified as center peak, flat, and saddle. Finally the selected function sets were applied to reference data to verify improvement of synthesis performance compared with conventional ones. It was found that synthesis by using the improved function sets was better than the conventional ones for predicting axial power distribution as given in **Table 1**.

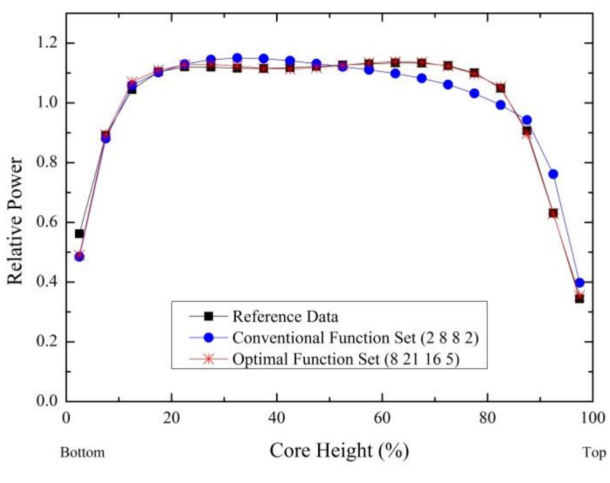

Figure 2. Synthesis Result of Axial Power Distribution

Table 1. Comparison of Synthesis Results by Conventional and Improved Function Sets

Shape	Conventional Function Set	Improved Function Set	Decreasing Rate of RMS error
Center	2 8 8 2	4 18 24 4	23.31 % (2.27→1.74)
		4 20 22 4	21.17 % (2.27→1.79)
Flat	2 8 8 2	5 22 21 4	4.45% (1.35→1.29)
		5 21 20 4	4.16% (1.35→1.29)
Saddle	2 8 8 2	4 23 19 4	19.59% (3.91→3.14)
		4 27 15 4	23.06% (3.91→3.01)

4. Conclusions

The axial power distributions were analyzed by using many types of cubic spline functions sets. From these analyses, optimal function sets in each power distributions are established. It was also found that cubic spline method can be improved using asymmetric and symmetric ones because asymmetric ones were evaluated as optimal sets for predicting the power shapes in many cases.

It is expected that an accurate expectation of core power by new function sets prevents unwanted reactor trip and it enhances the safety and economic of nuclear power plant. However, the study on developing detailed algorithm that can select better function sets should be progressed in future work.

Acknowledgment

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