Optimization of Gad Pattern with Geometrical Weight

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1. Introduction

The prevailing burnable absorber for domestic nuclear power plants is a gad fuel rod which is used for the partial control of excess reactivity and power peaking. The radial peaking factor, which is one of the critical constraints for the plant safety depends largely on the number of gad bearing rods and the location of gad rods within fuel assembly. Also the concentration of gad, UO_2 enrichment in the gad fuel rod, and fuel lattice type play important roles for the resultant radial power peaking. Since fuel is upgraded periodically and longer fuel cycle management requires more burnable absorbers or higher gad weight percent, it is required frequently to search for the optimized gad patterns, i.e., the distribution of gad fuel rods within assembly, for the various fuel environment and fuel management changes.

In this study, the gad pattern optimization algorithm with respect to radial power peaking factor using geometrical weight is proposed for a single gad weight percent, in which the candidates of the optimized gad pattern are determined based on the weighting of the gad rod location and the guide tube. Also the pattern evaluation is performed systematically to determine the optimal gad pattern for the various situation.

2. Gad Patterns with Geometrical Weight

2.1. Radial Power Peaking Factor

The main purposes of burnable absorber rod usage are excess reactivity control, radial peaking factor control and the moderator temperature coefficient control by reducing boron. The maximum radial peaking factor serves as a criteria for DNB and is determined basically as a product of nodal average power and form factor in APA[1,2] code system.

$$P_g(x,y) = \overline{P}_g \times P_g^{NEM}(x,y) \times \frac{P_{g,Het}^{Cell}(x,y)}{P_{g,Hom}^{Cell}(x,y)}$$

where,

$\overline{P}_g = Assembly\ (or\ nodal\ )\ Power$

$P_g^{NEM}(x,y) = Intra-Nodal\ Power\ Distribution\ for\ a\ Homogeneous\ Node\ predicted\ by\ 3D\ Nodal\ Code$

$P_{g,Het}^{Cell}(x,y) = Heterogeneous\ Assembly\ Pin\ Power\ predicted\ by\ 2D\ Cell\ Code$

$P_{g,Hom}^{Cell}(x,y) = Homogeneous\ Assembly\ Power\ Distribution\ predicted\ by\ 2D\ Cell\ Code$

Since $P_g^{NEM}(x,y)$ is determined based on nodewise surface flux and corner flux[1], it is dependent on the nodal solution and the location of assembly rather than the location of burnable absorber rod. Thus, the result of cell code calculation is one of the key factors for the final radial power peaking in the core depletion calculation.

2.2. Poison Effect

The poison effect of the burnable absorber is also a significant issue for the consideration of burnable absorber type which is evaluated based on the infinite multiplication factor of the cell code. However, for gad rods, the poison effect is not so a strong function of gad rod pattern within assembly, but a function of the number of gad rods or the contents of absorber material and the burnup as shown in Figure 1. which is a plot of the k-inf behavior for 24 gad rod patterns in a cell calculation. Also the cycle burnup of contemporary nuclear power plants are long enough to reduce the poison effect of the burnable absorber to the minimal.

Therefore, the radial power peaking factor is more dominant term for the determination of optimized gad pattern.

2.3. Pattern Spawning with Geometrical Weight

In order to determine the optimized gad pattern, the candidates of the gad pattern are spawned based on the geometrical weight method. Since thermal neutron peak is expected around the locations of guide tubes and instrumentation tube, also the locations of other gad rods are playing as a sink of thermal neutron, the geometrical weighting factor of each fuel rod location is proposed as follows:

$$w_i = \sum_j d_{ij}^2 + \sum_k \frac{G}{g_{ik}^2}$$

$w_i = geometrical\ weighting\ factor\ of\ gad\ pin\ position\ i$

$d_{ij} = distance\ from\ the\ guide\ thimble\ location\ j\ and\ pin\ position\ i$

$g_{ik} = distance\ between\ the\ other\ gad\ rod\ location\ k\ and\ pin\ position\ i$

$G = bias\ factor\ for\ gad\ rod$

The geometrical weight is to effectively measure the evenness of gad rod patterns to the guide tube location and to prevent superposition of gad rods with each other. G, the bias factor for gad rod varies per the number of gad rods and the lattice types such as 14x14, 16x16, and 17x17. It is determined based on trial and error to give the gad patterns of currently accepted with weighting factors of reasonably good ranks. For 17x17 fuel lattice, the values of G determined are shown as below:

Number of gad rod	G
4	10000
8	5000
12	2200
16	2000
20	1600
24	1200

For the generation of candidates the following assumptions are made from the heuristic approach.

- Octant mirror symmetry is maintained for the locations of gad rods within fuel assembly. For the asymmetric fuel lattice like 14x14, quarter assembly cyclic symmetry is assumed.

-Only quadruples of gad rods are considered

-The assembly periphery pin locations are excluded from the candidate.

The fuel pin locations are classified as D(Diagonal), C(Center), and I(Interior). The guide tube locations are named as G. Thus the fuel pin and guide tube locations are enumerated as follows for the octant of the assembly.

	1	2	3	4	5	6	7	8	9
1	X	X	X	X	X	X	X	X	X
2	X	D							
3	X	I	D			G			G
4	X	I	I	G					
5	X	I	I	I	D				
6	X	I	G	I	I	G			G
7	X	I	I	I	I	I	D		
8	X	I	I	I	I	I	I	D	
9	X	C	G	C	C	G	C	C	G

A program was written to generate possible patterns for all kinds of combinations of pin locations within assembly to evaluate the geometrical weight and 33111 patterns were evaluated for 24 gad rods, for example. The sample gad patterns for 24 gad and weighting factors are shown in the following table.

RANK	Quarter Assembly gad pattern						wi
1	(9, 2)	(9, 7)	(5, 2)	(2, 5)	(7, 5)	(5, 7)	15353.38
2	(9, 2)	(9, 7)	(5, 3)	(3, 5)	(7, 5)	(5, 7)	15373.84
3	(3, 3)	(9, 7)	(7, 2)	(2, 7)	(7, 5)	(5, 7)	15400.15
4	(9, 2)	(9, 7)	(6, 2)	(2, 6)	(7, 5)	(5, 7)	15407.99
5	(9, 5)	(3, 3)	(5, 5)	(7, 7)	(7, 2)	(2, 7)	15473.25
6	(8, 8)	(9, 2)	(5, 2)	(2, 5)	(7, 5)	(5, 7)	15559.66
7	(5, 5)	(9, 2)	(9, 5)	(9, 7)	(6, 2)	(2, 6)	15560.52
8	(5, 5)	(9, 2)	(6, 2)	(2, 6)	(8, 6)	(6, 8)	15569.04
9	(8, 8)	(9, 2)	(5, 3)	(3, 5)	(7, 5)	(5, 7)	15576.81
10	(9, 2)	(9, 7)	(5, 2)	(2, 5)	(7, 4)	(4, 7)	15580.21

3. Pattern Evaluation

Of all the patterns evaluated with geometrical weight, top most 200 candidates were selected for the final pattern evaluation using cell code. For the cell calculations, PHOENIX-P[2] was used and job deck generation and running of the code were automated through a simple C program and the script. The output edits were done using the script code and radial pin peaking was evaluated for all the patterns of consideration.

4. Results and Conclusions

The cell code pattern evaluation results were shown in Figure 2 and 3. In Figure. 2, peak pin power vs burnup for 20 gad patterns of top 10 ranks were shown and the results indicate that the maximum peaking variation is around 0.03 and the optimal patterns are dependent upon the time of interest. Figure 4 shows that the peak pin power for 24 gad patterns of assorted ranks among top 200 weight. The maximum variation in peak pin powers are increased to around 0.6 but after 12K MWD/MTU the variation is negligible. The results indicate that the first stage screening using geometrical weight is effective for the optimization of gad rod patterns. However, the results also indicate the patterns of similar weight show different patterns of peak variation and the best pattern that satisfies all kinds of situations is not plausible and for the optimized pattern more than 200 candidates should be considered. Therefore the optimized gad patterns may vary according to the number of gad rods, the time of peak, and the location of fuel assembly.

In this study, the systematic approach to determine the optimized gad patterns using geometrical weight is proposed and evaluated to be quite effective for the various situations of enrichment change, fuel upgrades, and fuel management changes. Thus loading pattern dependent optimization is possible through this method.

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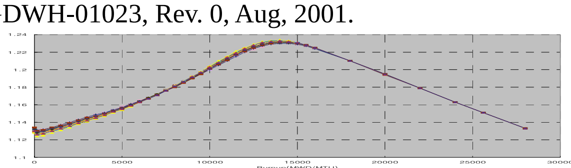

Figure 1. k-inf for 24 gad rod patterns in 17x17 fuel lattice

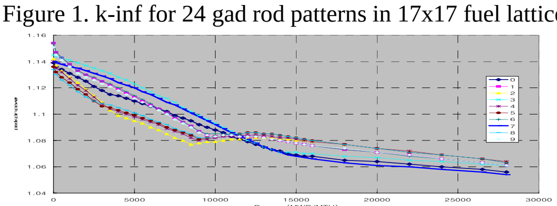

Figure 2. Peak pin power for 20 gad patterns of top 10 ranks

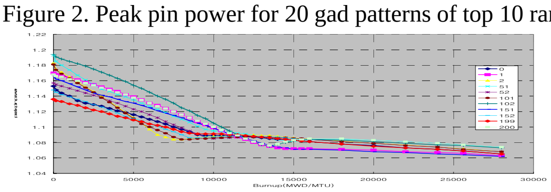

Figure 3. Peak pin power for 24 gad patterns for assorted ranks among top 200