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3. BWR Control Rod Programming Using Heuristic and Mathematical Methods, *Tamotsu Hayase, Hiroshi Motoda (AERL-Japan)*

OPROD,[1] a computer code for BWR control rod programming, has successfully been applied in actual practice in a medium-sized commercial BWR for a period of three operating cycles. During recent application in a larger BWR loaded with nonuniformly distributed gadolinia fuel, some difficulties have been encountered that are mostly due to stronger heterogeneity and increased power density of the larger BWR. The problem actually lies in finding a feasible solution, not an optimal. Even an elaborately chosen initial guess sometimes falls far out of the feasible region. To overcome these difficulties, a heuristic approach has been developed and coupled as a PRE-MAP routine to the original MAP routine in which a small improvement was also implemented.

The PRE-MAP routine was designed to find a feasible solution and to search for a rod pattern that improves the core characteristics with respect to the severest constraint. The main characteristic of this heuristic approach is its ability to grasp the core as a whole and, in that way, to determine a pattern that is more rational and geometrically better arranged than other mathematically programmed methods, even starting from an all-rods-out guess.

Control rods are grouped deep and shallow. This search is basically one with two degrees-of-freedom. The rods are always split into two subgroups and the rods within each subgroup are moved in the same direction for the same distance. The search is made with a small criticality allowance. The two subgroups are redefined in going from step 1 (rough adjustment) to 3 (fine adjustment) in accordance with rod pattern improvement.

Step 1: Criticality Search

The deep and the shallow rods are formed into two subgroups. The former is used to decrease the reactivity and the latter to increase the reactivity.

Step 2: Improvement of Core Characteristics by Deep Rods Search

The deep rods are divided into as many groups as necessary, out of which two subgroups are formed in the following manner:

1. Divide all the groups into two subgroups and search for a rod pattern that gives the best core characteristics.

2. Make ranking of the core characteristics throughout the regions associated with these groups, and form two new subgroups by selecting the highest and the lowest ranking groups. Then, search for the best rod pattern.

3. If the pattern obtained is an improvement over the starting pattern, go back to point 2. If not, form a new subgroup by combining the highest and the second highest ranking members and continue the search for the best pattern. If the best pattern obtained is an improvement, go back to step 2. If not, go to step 3.

Step 3: Fine Adjustment of Deep and Shallow Rods

If the last rod pattern obtained falls in the feasible region, go to MAP routine. If not, adjust the deep and shallow rods nearest to the location where the core characteristics are the worst.

The MAP routine was designed to find (starting from a feasible or near feasible solution) an optimal pattern that gives the power distribution which is the closest possible to the desired target power distribution. If the starting pattern is in the feasible region, the standard MAP is used. If not, unsatisfied constraints are temporarily relaxed and the flow goes into the MAP. These relaxed constraints are gradually tightened in the process of iteration.

This method was successfully applied to the first cycle of an 800-MW(e) BWR, having three different enriched fuel assemblies with axially distributed gadolinia. Figure 1 shows the search process during each of the previously mentioned steps. In this example, MCHFR is the severest constraint of all and the initial guess pattern selected was all-rods-out. A feasible rod pattern could be found during the course of step 2. In all other cases, the situation was about the same and so far no case has been experienced in which the search process failed in finding a feasible solution.

1. T. KAWAI, H. MOTODA, T. KIGUCHI, and M. OZAWA, *Nucl. Technol.*, 28, 108 (1976).

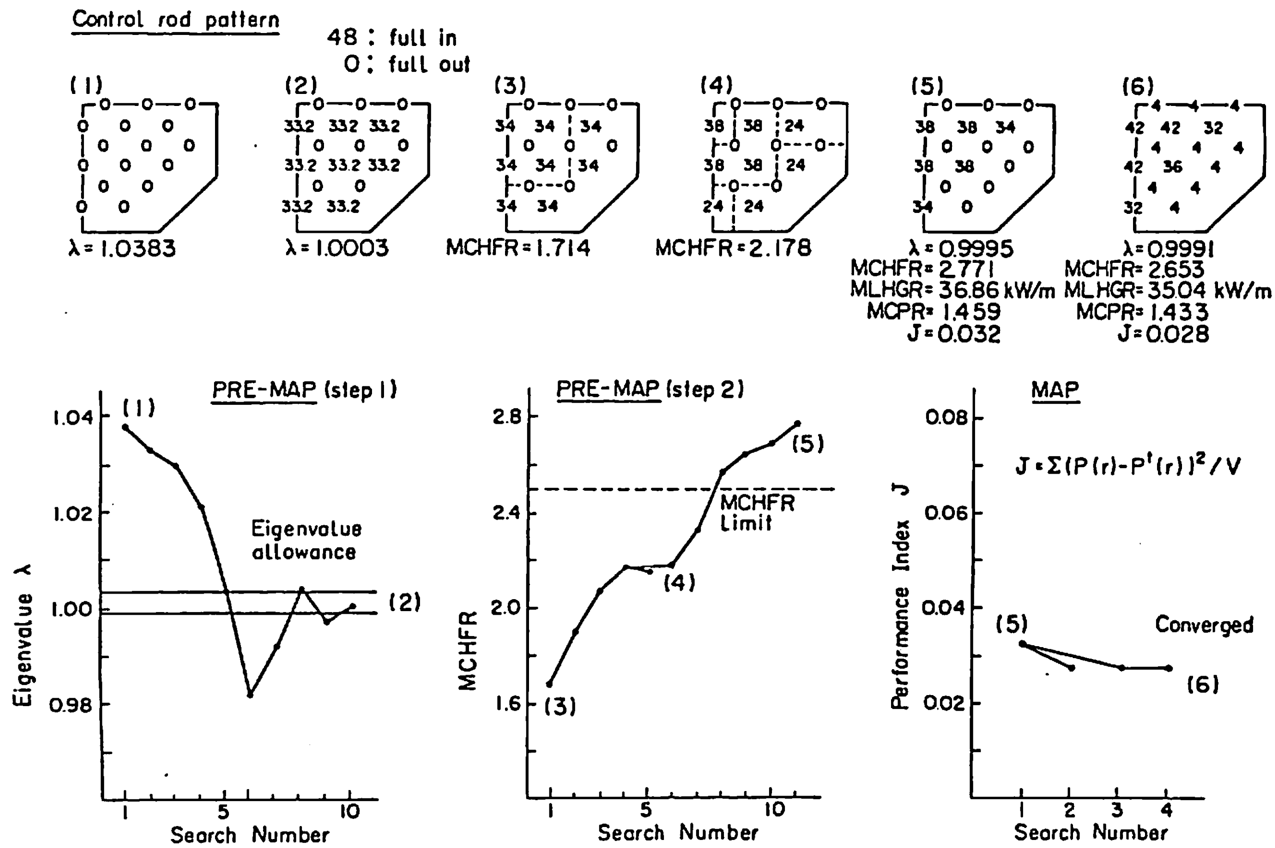

Fig. 1. An example of searching process during each step.