Analysis of a 12-Finger Rod Drop using RETRAN/MASTER Code System for APR1400

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1. Introduction

The Optimized Power Reactor 1000 (OPR1000) has 4-finger and 12-finger Control Element Assemblies (CEAs). When the 12-finger CEA is dropped, Core Protection Calculator System (CPCS) shuts down the reactor to prevent fuel damage that could occur from the sudden reactor power peaking. By contrast, the improved CPCS of Advanced Power Reactor 1400 (APR1400), which has systems similar to those of the OPR1000, decreases reactor power rapidly using its Reactor Power Cutback System (RPCS) to avoid unwanted reactor trips caused by the CPCS during a 12-finger CEA drop event.

RETRAN is a best-estimate code for transient analysis of Non-LOCA. The RETRAN control logic, which includes the function of reducing reactor power during a 12-Finger CEA drop, has been developed for the APR1400. A MATRAN program has also been developed. MATRAN is the interface program for real-time processing to connect RETRAN with MASTER code which is a nuclear analysis and design code. MATRAN supplies adequate feedback reactivities from the MASTER code to RETRAN code.

The purpose of this study is to analyze the behavior of a nuclear reactor core and its primary system using conventional RETRAN analysis procedure and MATRAN program analysis procedure during a 12-finger CEA drop. In addition, the axial power distribution and Axial Shape Index (ASI) are produced by the MATRAN program and they are confirmed as within operation limits.

2. System Interface for a 12-Finger CEA Drop Event

2.1 Interface RETRAN with MASTER

RETRAN [1] generates neutron number densities in the core using a point kinetics model which includes kinetics parameters and feedback reactivities. Before transient analysis using RETRAN, it is necessary for the nuclear design code to generate nuclear design data for the point kinetics model. Conventionally, these data are provided by the nuclear design code only once. Consequently, the nuclear data of this procedure is conservative and does not represent the exact value of various transient reactor statuses.

The MATRAN program interfaces RETRAN with MASTER [2] in real time. The interface procedure between RETRAN and MASTER is detailed below.

First, the MATRAN program analyzes the system status using RETRAN until the interface start time and generates reactor power and thermal-hydraulic parameters such as reactor inlet/outlet temperatures and flow rates. The MATRAN program also generates feedback reactivities using MASTER according to changed reactor power. Then, using the RETRAN restart option, the MATRAN program replaces the moderator density reactivity and fuel temperature reactivity with new ones. Finally, MATRAN runs RETRAN to analyze the transient system status for the next time step. This procedure is iterated for a given period.

2.2 Simulation of a 12-Finger CEA Drop Event

The CPCS of the APR1400 has been improved to initiate RPCS operation and reduce reactor power during a 12-Finger CEA drop event. This function has also been applied to the system logic of RETRAN for the APR1400 12-Finger CEA drop event simulation. The initial condition and interface time of the MATRAN program are shown in Table 2-1. After a 12-Finger CEA drops at 110 sec. and RPCS CEA drops at 111 sec., the MATRAN program runs MASTER with new system parameters and reactor power at 112sec. Then, the MATRAN program runs RETRAN with new feedback reactivities at 113 sec. This procedure continues every second for about 400 seconds. In addition, Reactor Regulating System (RRS) maneuvers the regulating CEA to meet the balance of the primary and secondary sides after the RPCS actuates at 111 sec.

Table 2-1: Initial Condition and Interface Time of MATRAN Program

Initial Condition	Power	3983MWth
	Reactor Inlet Temp.	290.7℃
	Reactor Outlet Temp.	323.8℃
RETRAN (0~112 sec)	Steady State(ARO)	0~110 sec
	A 12-Finger CEA Drop	110 sec
	RPCS CEA Drop	111 sec
MATRAN (Interface : MASTER, RETRAN	runs MASTER with reprocessing input	112 sec
	runs RETRAN with reprocessing input	113 sec
MATRAN (Iteration)	Time step(1 sec)	113~114 sec

2.3 Axial Power Distribution during a 12-Finger CEA Drop Event

MATRAN generates the core average ASI using MASTER which is consisted of 26 axial nodes. The ASI is computed from FZBOT and FZTOP and is used to determine the power peaking adjustment factors.

$$\mathrm{ASI} = \frac{\mathrm{FZBOT} - \mathrm{FZTOP}}{\mathrm{FZBOT} + \mathrm{FZTOP}}$$

$$FZBOT = \sum_{i=1}^{13} FZ_i \,, FZTOP = \sum_{i=14}^{26} FZ_i$$

Where FZ_i = relative axial power in the i^{th} node
FZBOT = power in the bottom half of the core
FZTOP = power in the top half of the core

3. Results

The 12-Finger CEA drop simulation of the APR1400 was performed using the MATRAN program. The simulation results are compared with those of the conventional procedure using RETRAN for system transient analysis.

Table 3-1 shows the total reactivities from 112 sec. to 137 sec. The total reactivities include the moderator density reactivity, Doppler reactivity and regulating CEA reactivity. The CEA position of the reactor regulating system, for both MATRAN and RETRAN, is the same from 112 sec. to 137 sec. In Table 3-1, the absolute reactivities of the MATRAN program are slightly greater than those of the conventional RETRAN procedure. This means that the feedback reactivities of the MATRAN program, including the moderator density and Doppler reactivities, are greater than thoes of the conventional RETRAN procedure. Due to the feedback effect, the reactor power of the MATRAN program is smaller than that of the conventional RETRAN procedure. Figure 3-1 shows the power change of the 12-Finger CEA drop simulation.

Table 3-1: Total Reactivity of RETRAN and MATRAN

Time(sec)	MATRAN ($)	RETRAN ($)
112	-0.1835	-0.1835
117	-0.2603	-0.2091
122	-0.1392	-0.1124
127	-0.0986	-0.0875
132	-0.0902	-0.0781
137	-0.0795	-0.0722

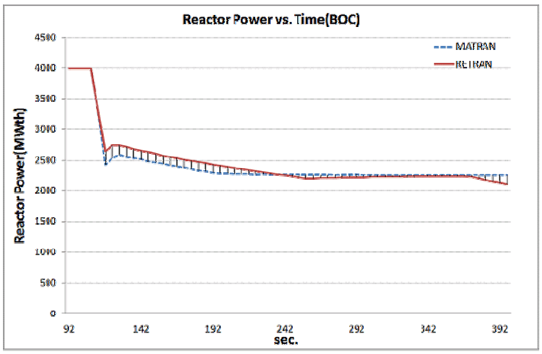

Fig 3-1. Power Change of a 12-Finger CEA Drop Simulation for APR1400 from 92 sec. to 397 sec.

The MATRAN program also generates an axial shape index. In Figure 3-2, after the 12-Finger CEA and RPCS CEA drop at the beginning of the cycle (BOC) and the end of the cycle (EOC), the ASI is increased sharply. This means the axial power shape is the bottom peak because of regulating the CEA insertion from top to bottom. The ASI is then decreased because the change of the inlet/outlet temperature affects negative feedback. That is, according to the decrease of outlet temperature, the reactor power of the upper region is increased due to the negative feedback reactivity. At EOC, in particular, the moderator temperature coefficient is much bigger than at BOC. In addition, after the axial power shape moves toward upper reactor, it is gradually shifted to the lower region again because the reactor-regulating CEA is being inserted into the upper region. At the BOC, the regulating CEA is being inserted from 240 step to 187.7 step and is inserted to 75.5 step at the EOC. All of the ASIs at the BOC and at the EOC are within ±0.2, from 92 sec. to 397 sec., which is within the operating limits.

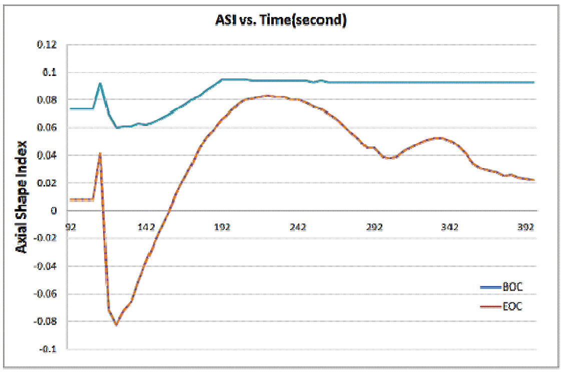

Fig 3-2. Axial Shape Index Change of a 12-Finger CEA Drop Simulation for APR1400 from 92 sec. to 397 sec.

4. Conclusions

A system and core analysis of a 12-Finger CEA drop simulation for the APR1400 was performed using the conventional RETRAN procedure and the MARTRAN program. According to the relative results of reactor power, immediately after a 12-Finger and RPCS CEAs drop, reactor power of conventional RETRAN procedure is bigger than those of MATRAN program procedure. This means the conventional RETRAN procedure is more conservative for safety analysis because it is more probable that nuclear fuel is damaged in higher power level.

In addition, the tendency of axial power shape is simulated during a 12-Finger CEA drop, RPCS CEA drop and regulating CEA insertion. And it is confirmed that ASI values are within the range of core operation.

REFERENCE

[1] “RETRAN-3D : Theory and Numerics”, COMPUTER SIMULATION & ANALYSIS, INC, July 2001.
[2] “MASTER3.0 USER’S MANUAL”, KAERI, March 2004.