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Research reactor operation simulation for Control Rod Drive Mechanism endurance test plan

Donghyun Kim [a*] and Suki Park [a]
[a] *Research Reactor Design Division, KAERI, Daedeok-daerho 989-111, Yuseong-gu, Daejeon, 34057*
[*] *Corresponding author: dhkim1113@kaeri.re.kr*

1. Introduction

A Control rod drive mechanism (CRDM) is an assembly of devices to control the position of control rods. Receiving the signals transferred from a power control system, the CRDM inserts or withdraws the control rod using a step motor. Since it is important to the nuclear safety and performance of research reactors, the durability of the CRDM shall be guaranteed for a certain period of time through the endurance test. And, a replacement period can be also determined from the test results.

The tests are performed based on a stepping regime The stepping regime means the expected stepping movements of a step motor in CRDM through the quality guaranteed time, which is expressed in 'cycles' and 'steps/cycle'. A cycle is the processing period from the core status check, control rod movement command signal generation to actuation of the step motor. The steps/cycle is a stepping number of the step motor per cycle, i.e. control rod insert/withdrawal speed.

To obtain the stepping regime, it is necessary to simulate the behaviours of the reactor and control system from the startup to the shutdown operation. If power change occurs, power control system generates the signals to move the step motor for power control. Since reactivity change causes power perturbation, all factors to cause the reactivity change must be considered to make a reasonable operation simulation. From the simulation results, the stepping regime is derived.

In the previous study[1], the methodology for developing CRDM endurance test plan was suggested. Herein, an appropriately modified methodology is proposed and, stepping regime is derived by simulating an example of a research reactor.

2. Simulation program and input data

2.1. Simulation Program

Reactor Regulating System SIMulator(RRSSIM) is used to simulate transient reactor and control system behaviors. The program was developed using MATLAB/SIMULINK[2]. For simulating the reactor, a multiple kinetics and dynamics models are included in the program[3].

2.2. Models and input data

The neutron kinetics, thermal dynamics, Xenon transient, power control system models are implemented in the simulation program. The simplified diagram of the models in simulation program is shown in Fig 1.

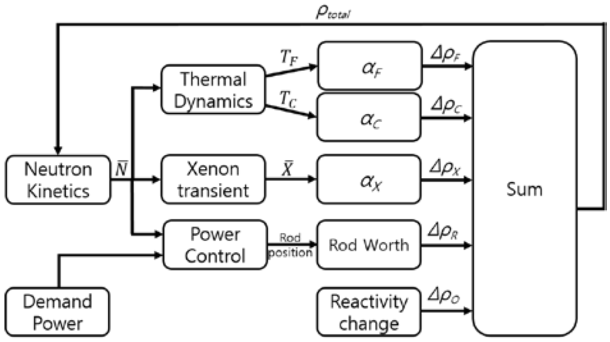

Fig.1 Diagram of models in RRSSIM program

The neutron kinetics is modeled using point kinetics. The point kinetics equations are following as below.

$$\frac{dN(t)}{dt} = \frac{\rho(t)-\beta}{\Lambda}N(t) + \sum_{i=1}^{I}\lambda_{C_i}C_i(t) + S$$

$$\frac{dC_i(t)}{dt} = \frac{\beta}{\Lambda}N(t) - \lambda_{C_i}C_i(t)$$

Prompt neutron generation time, yield fractions of delayed neutrons and decay constants for precursor groups are provided as input.

Thermal dynamics in core region is simply modeled as follows

$$M_{FE}C_{FE}\frac{dT_{FE}}{dt} = \eta_F Q_C - H_F(T_F - T_C)$$

$$M_C C_C \frac{dT_C}{dt} = (1-\eta_F)Q_C + H_F(T_F - T_C) - W_C C_C (T_{CO} - T_{CI})$$

Initial core inlet and outlet temperature, fuel and coolant properties, thermal power, a fraction of heat absorbed in fuel elements are provided as input.

To consider Xenon poisoning effect at equilibrium Xenon status, Xenon concentration is modeled as balance equations as follows.

$$\frac{dI}{dt} = \gamma_I \Sigma_f \phi - \lambda_I I$$

$$\frac{dX}{dt} = \gamma_X \Sigma_f \phi + \lambda_I I - (\sigma_{aX}\phi + \lambda_X)X$$

Decay constants, effective decay constants, yield fractions are provided as input.

Control logic in the power control system is modeled. Control algorithms are implemented in power control system to regulate the power according to power demand. The control system identifies the difference between the present power and the demand power and, generates a signal commanding the CRDM how far to move the control rod within the proper speed range to regulate the power. When the position of the control rod is changed, reactivity is inserted by the control rod.

The reactivity feedbacks are calculated from following equations based on the amount of change of parameters calculated from the models described above.

$$\Delta\rho_F = \alpha_F \Delta T_F$$
$$\Delta\rho_C = \alpha_C \Delta T_C$$
$$\Delta\rho_X = \alpha_X \Delta\overline{X}$$
$$\Delta\rho_R = \text{Rod worth}(\Delta x)$$

Fuel and coolant temperature coefficients, reactivity worth due to equilibrium Xenon, initial control rod position and control rod worth are provided as input.

2.2.3. Reactivity change

The reactivity change part directly inputs the reactivity worth in response with time in the form of a table. First, reactivity changes due to fuel depletion and Xenon build-up at the beginning of operation are provided in this form. The next is reactivity worth due to the irradiation targets. In accordance with the purpose of the research reactor, the irradiation targets can be loaded or unloaded during power operation. When the targets are loaded or unloaded, the reactivity of the core changes. Therefore, reactivity worth due to the irradiation targets with time is set according to the research reactor utilization plan.

In this simulation, on-power loading and unloading of various types of the irradiation target are assumed as given in utilization plan. The maximum number of loading and unloading irradiation targets shall be assumed for the endurance test plan.

3. Simulation Methods

The simulations are performed by dividing into the startup operation, the full power operation, and the shutdown operation. In the case of the startup operation and the shutdown operation, the reactor is operated by increasing or decreasing the power from/to the zero power to/from the full power according to the operation procedure. When simulating the startup and the shutdown operation of the reactor, the demand power over time is provided as input.

The simulation is performed from the startup to the shutdown operation using an example of a research reactor. The range of step number is assumed to be -15~+15steps/cycle.

4. Results and discussion

Figure 1 shows the power perturbation for an operation period from the startup to the shutdown of the reactor. At the startup, power increases from zero to full power. It occurs on the contrary at the shutdown of the reactor. During full power operation, the power oscillates at low amplitude, since the reactivity is changed due to on-power loading and unloading of the irradiation targets.

Figure 2 shows the stepping regime graph of the CRDM with a log scale. Since a lot of vibration of power with small amplitude occurs due to irradiation targets, the number of cycles with low numbers of steps/cycle (-2~+2) is obviously large compared to the others. And also, the number of the cycle with positive or negative 15steps/cycle, indicating bars at both ends of the graph, is large since the control rod is inserted or withdrawn with high speed to change the power rapidly

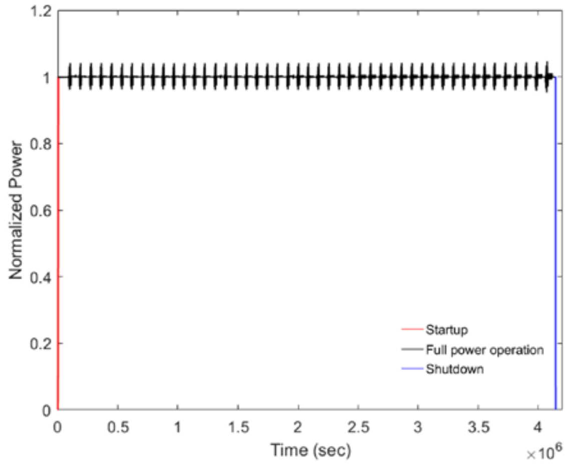

Fig.1 Power changes during simulation.

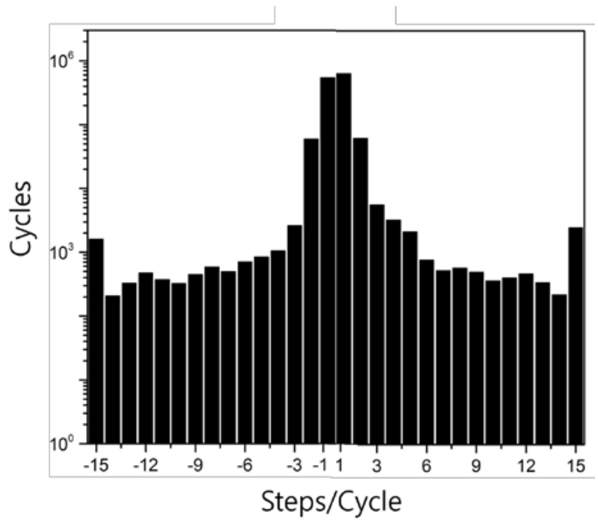

Fig.2 Stepping regime derived from the simulation results.

in the startup and the shutdown. The total number of the cycle with positive steps/cycle (control rod withdrawal) is larger than the one with negative steps/cycle (control rod insertion) due to the fuel depletion effects.

5. Conclusions

In previous study, the stepping profile of the CRDM during power operation was estimated taking into account the simulation results of the reactor operation at particular points in time. But the effects such as fuel depletion and Xenon build-up can not be considered properly in this case.

In present study, it is proposed that the stepping regime is derived from the simulations of the reactor operation including the startup and the shutdown, rather than estimation. The example of the entire process is introduced using the typical research reactor with an assumption of operation procedures and reactor utilization plans.

Acknowledgement

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