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Development of Stepping Endurance Test Plan on CRDM of a Research Reactor

DongHyun Kim [a], Hyeonil Kim [b*], Suki Park [a]
[a] *Research Reactor Safety Analysis, KAERI, Daedeok-daerho 989-111, Yuseong-gu, Daejeon, 34057*
[b] *Research Reactor Technology Management, KAERI, , Daedeok-daerho 989-111, Yuseong-gu, Daejeon, 34057*
[*] *Corresponding author: hyeonilkim@kaeri.re.kr*

1. Introduction

Key performance of components such as Control Rod Drive Mechanism, CRDM, of great importance to the nuclear safety and performance of research reactors [1], should be guaranteed through the life time or a certain period of research reactors by a series of qualification tests (Functional check, drop performance, stepping performance, seismic test, endurance, vibration measurement and inspection) reflecting operational characteristics of the components.

Of tests, stepping endurance test is to demonstrate the structural integrity, wear and performance reliability. Endurance of stepping motion is strongly related to the operational characteristics of a specific research reactor with a capability to load and unload irradiation targets especially for Fission Moly production during power operation. And physical characteristics of the reactor and controller algorithm driving motors profoundly affect on the endurance. Therefore, it is necessary to model and evaluate those characteristics for the test planning of stepping motion.

Various types of the irradiation targets can be loaded and unloaded during power operation, according to the purpose of research reactor utilization. And their reactivity worth varies as well. The insertion rate of reactivity is dependent to reactivity worth of targets, travel length during loading or unloading and transfer device speed. Due to the reactivity transition during loading and unloading, neutron power is changed and reaches an action point of the reactor regulating system. Based on the measured neutron rate of change, reactor power control system controls the power with its own algorithm. It generates the signals and transmits these to the CRDM for motor driving. Stepping motors on the CRDM move the control rods with step signals. The process repeats until power is stabilized. Accordingly, the stepping behaviours of CRDM should be modelled upon an understanding of the control process and reactor responses.

For supporting the establishment of stepping endurance test plan, a simulation program is used to mimic transients of a research reactor, which is based on a set of generic design features such as the control rod worth, performance of the drive mechanism, and controller in the reactor power regulating system, which are essential for controlling the reactor[2][3]. Finally stepping behaviour is estimated from the analysis of simulation results.

2. Methods for estimation of operating history

The dynamic models for a reactor transient simulation include neutron point kinetics, Iodine-Xenon behavior, reactor/thermal power from a core and the reflector, reactivity feedback, and controller, and the individual component models of the reactor are incorporated into a simulation program of the RRSSIM, Reactor Regulating System Simulator[3]. The program was originally developed in FORTRAN, but was modernized in MATLAB/SIMULINK[4] for enhancing its flexibility to construct a virtual reactor with all of the components. The simplified diagram of the simulation program is shown in Fig 1.

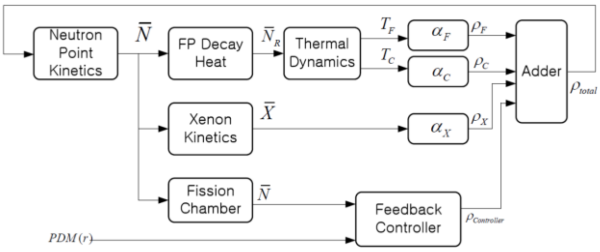

Fig. 1. Simplied diagram of simulation

2.1 Neutron Point Kinetics

To describe the reactor kinetics, point kinetics is used[5]. The point kinetics is the space-independent kinetics equations handling one group of neutron energy. As the delayed neutron precursors are treated in six groups, point kinetics equations are following as below.

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

$$\frac{dC_i(t)}{dt} = \frac{\beta}{\Lambda} N(t) - \lambda_{C_i} C_i(t),\ i = 1, \ldots, 6 \quad (2)$$

2.2 Initial conditions

Initial conditions are essential to simulate transients of the system, which shall be appropriate values to represent physical characteristics in modelling case. Specially, the initial control rod position, in addition to the initial power and initial temperature, should be crucial to the instantaneous response of the system because the typical rod worth in a differential form is as shown in Fig 2 [6]: with respect to the initial position of a rod, the differential rod worth for controlling reactivity of the reactor is outstandingly different depending on the position from the BOC through EOC.

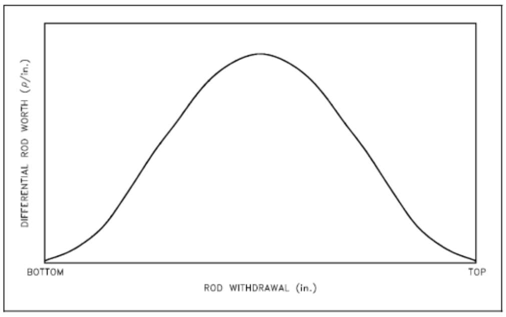

Fig. 2. Conceptual differential control rod worth

2.3 Reactivity Feedback

Reactivity feedback is considered to be due to variations in fuel, coolant, reflector, and xenon load. Simply modelled thermal dynamics is to calculate temperature variation in fuel and coolant leading to reactivity feedback. The feedback of xenon build-up comes from xenon dynamics which is the time dependent concentrations of iodine and xenon.

2.4 Loading and unloading of irradiation targets

In conservative point of view, maximal loading and unloading schedule of irradiation targets should be assumed considering irradiation time, limiting condition such as maximum allowed reactivity, and operating procedure. Based on the maximum loading and unloading, irradiation schedule for a certain period of operating time can be divided into unit pattern repeated periodically for which the simulations are to be performed. It is convenient to simulate the transient by applying time-dependent initial condition such as control rod position in order to shorten simulation time.

When modelling the procedure of loading and unloading of irradiation targets, reactivity worth and insertion rate of it should be considered. Each reactivity worth of irradiation target is necessary according to the reactor state. To model the reactivity insertion rate of each irradiation target, it is essential to consider the loading position and the speed of transfer devices or the system transferring targets to the active core region.

2.5 Controller

The response of a reactor system to an external disturbance such as reactivity insertion is managed by a controller such as reactor power control system. Control algorithm is specified by predetermined logic and tuned to optimize the control ability.

2.6 Number of stepping times

Operation of a research reactor consists of startup, power operation for producing radioisotopes, and shutdown. When changing the operation mode, control rod moves with large stepping times. And stepping motor keeps being driven by controller during power operation to control the power perturbation by loading and unloading the irradiation targets.

The stepping times should be dependent to the differential control rod worth which is changed from BOC to EOC. Conceptual relation between number of stepping times and differential rod worth with operating time of a cycle from BOC to EOC is shown in Fig 3. The smaller the differential rod reactivity is with a cycle, the more the control rod moves to response with the same reactivity.

It is desirable to input the initial rod position corresponding the core state at each time of a cycle. But those are inconvenient time-consumer works. To prevent this, stepping times can be estimated using the relation presented in Fig 3.

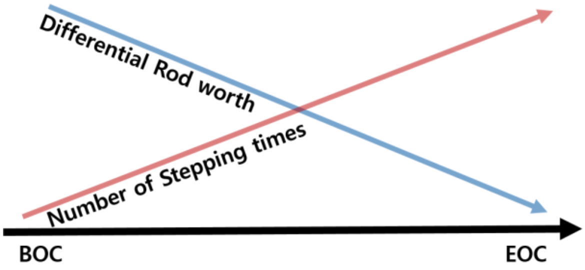

Fig. 3. Conceptual relation between number of stepping times and differential rod worth with time of a cycle from BOC to EOC.

3. Results and discussion

3.1 Operating History during power Operation

Simulation was performed for an example of transient assuming loading of a number of irradiation targets in one day of unit pattern. The results are shown in Fig 4 and 5.

When irradiation targets with positive reactivity are loaded into the core, normalized power rapidly increases and step signals are generated to drive the control rods. And then, power keeps perturbed with a small range leading to step signal generation with 1 or -1.

Summation of values of step signals is the number of stepping times in unit pattern. To calculate the stepping times for a cycle from BOC to EOC, the stepping times in unit pattern is multiplied by the number of unit pattern in a cycle. And also the weighting factor should be applied to the each of stepping times in unit pattern considering description in 2.6. For the number of stepping times in operating lifetime, the stepping times in a cycle is multiplied by the number of cycle in operating lifetime

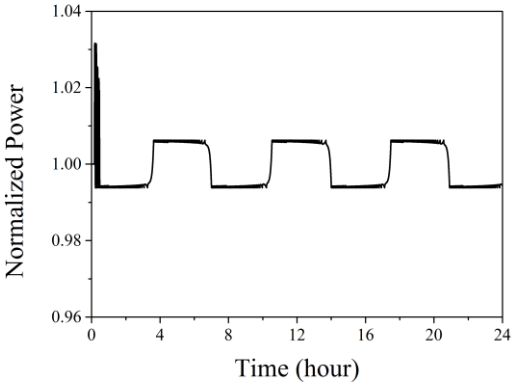

Fig. 4. Normalized power(Present power/Power demand)

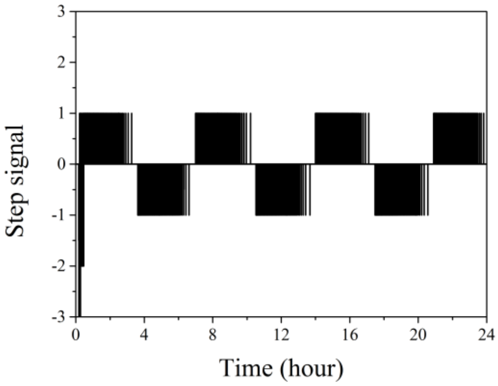

Fig. 5. Step signals generated by Reactor Power Control System

3.2 Comparison with Rough estimation

If the reactor power control system compensate instaneously for the change of reactivity to maintain the demand power, the number of stepping times can be calculated roughly with diffrential rod worth and distance per step. Compared with the result of simulation, the summation of values of step signals in Fig 5, it is small by factor of a third because small perturbation of power continues even after reactivity distrubance is managed.

4. Conclusions

Methodology for a stepping endurance test plan on the CRDM of a research reactor is developed since CRDM endurance is very important for reactor controller and should be ensured for a certain period of time throughout the life of a research reactor. Therefore, it is expected to provide a reasonable stepping test plan. In the future, the simulation will be performed with specific design values.

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