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Verification and Application of MASTER for Load Follow Operation

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Abstract

The xenon dynamics module in the nuclear design code MASTER was verified through a simulation calculation. The simulation result shows that the xenon dynamics module in MASTER can trace and predict xenon behavior with accuracy under any core transient state and therefore can simulate load follow operations.

1. Introduction

During reactor operation the reactor core can be placed in a slow transient state induced by load follow operations. Such a behavior can be traced using the xenon dynamics module in the nuclear design code MASTER [1] which was developed by KAERI for the application to reactor physics analyses of pressurized water reactors. The purpose of this paper is to show that the xenon dynamics module in MASTER can trace and predict xenon behavior with accuracy under any core transient state and therefore can simulate load follow operations.

2. Theory

The xenon dynamics module solves the time-dependent iodine/xenon and optionally the promethium/samarium differential equations. The solution methods for the transient flux calculation module are identical to those of steady-state flux calculation module in MASTER except for the additional solution methods regarding time discretization[1]. The time discretization will be performed by means of Hermite polynomials. The nodal flux shapes are approximated by linear functions in each considered time intervals. For each time step the calculation of the iodine/xenon and optionally the promethium/samarium concentrations is performed iteratively together with the steady state flux solution process. The iteration process is performed until the flux shapes and their concentrations are converged.

2.1 Time Dependent Equations

The xenon dynamics module solves the time dependent iodine/xenon equations

$$\frac{dI}{dt} = \gamma_I(\sum_g \Sigma_f^g \phi^g) - \lambda_I I \qquad (1a)$$
$$\frac{dX}{dt} = \gamma_X(\sum_g \Sigma_f^g \phi^g) + \lambda_I I - (\lambda_X + \sum_g \sigma_x^g \phi^g)X \qquad (1b)$$

and optionally the promethium/samarium equations

$$\frac{dP}{dt} = \gamma_P(\sum_g \Sigma_f^g \phi^g) - \lambda_P P \qquad (2a)$$
$$\frac{dS}{dt} = \lambda_P P - (\sum_g \sigma_s^g \phi^g)S \qquad (2b)$$

where

- I concentration of iodine
- X concentration of xenon
- γ_I yield of iodine
- γ_X yield of xenon
- λ_I decay constant of iodine
- λ_X decay constant of xenon
- σ_X^g absorption cross section of xenon, group g
- P concentration of promethium
- S concentration of samarium
- γ_P yield of promethium
- λ_P decay constant of promethium
- σ_S^g absorption cross section of samarium, group g

Equations (1) and (2) are given and to be solved for each core node *m*. For more clearness, the index *m* has been omitted in the above equations.

2.2 Time Discretization

For the solution of (1*a*-*b*) and (2*a*-*b*) the flux shape in a considered time interval is approximated by linear polynomials. In this case the equations (1*a*) and (2*a*) can be generally written as

$$\frac{dI}{dt} = a_0 + a_1(t - t_0) - \lambda_I I \qquad (3a)$$
$$\frac{dP}{dt} = b_0 + b_1(t - t_0) - \lambda_P P \qquad (4a)$$

from which it follows that the equations for *I* and *P* can be solved analytically by

$$I(t) = c_0 + c_1(t - t_0) + e^{-\lambda_I(t - t_0)} \qquad (5a)$$
$$P(t) = d_0 + d_1(t - t_0) + e^{-\lambda_P(t - t_0)} \qquad (6a)$$

The coefficients c_i and d_i can be determined from the coefficients a_i and b_i by comparison of the coefficients of the related equations if the expressions (5a) and (6a) are inserted into (3a) and (4a), respectively.

Once the concentrations I_{k-1} and P_{k-1} for a considered time t_{k-1} are known, the time discretization of (1b) and (2b) is performed by means of Hermite polynomials. If (1b) and (2b) are written in the general form

$$\dot{y} = g(y, t)$$

the time discrete equations for (1b) and (2b) read now

$$y_{k+1} = y_k + \frac{\Delta t_k}{2}(g_{k+1} + g_k) - \frac{\Delta t_k^2}{12}(\dot{g}_{k+1} - \dot{g}_k) + R \qquad (3)$$

where

k time step index
Δt_k time step
R remaining error term

The remaining error term R is of 4th order which shows the high accuracy of the discrete equations (3).
If

$$\phi_k = \phi(t_k)$$
$$X_k = X(t_k)$$
$$S_k = S(t_k)$$
$$C_{k-1} = \frac{\phi_k - \phi_{k-1}}{\Delta t_{k-1}}$$

then the consistent calculation of concentrations and neutron fluxes

$$\phi_{k+1} = \phi(t_{k+1})$$
$$X_{k+1} = X(t_{k+1})$$
$$S_{k+1} = S(t_{k+1})$$

for the new time interval (t_k, t_{k-1}) can be performed by the iteration process.

3. Application for Xenon Oscillation Test in YG-3 Cycle 1

To verify xenon dynamics module in MASTER, a simulation calculation was made for Yonggwang Unit 3 Cycle 1 startup test in which a wide variety of core transients including power, boron and control rod change had been observed as illustrated in Figure 1. The time span of the simulation calculation ranges from October 20th to December 31th, 1994 and a xenon oscillation test was performed at December 17th, 1994. As seen in Figure 2, the xenon oscillation test was made by fully inserting control banks 5, 4 and P to bottom and then withdrawing them to top of core. The boron concentration and power during the test were kept around 820 ppm and 50 percent power, respectively. Axial Shape Index (ASI) variation was measured for the whole transient from the on-line monitoring system COLSS [2].

A simulation calculation was made by MASTER in three-dimensional quarter core geometry. Considered were the whole spectrum of the core data measured even at every 20 seconds. Although it is possible to calculate both the steady-state depletion and transient-state in sequential or mixed manner, only the transient calculation was made since the core burnup effect had been found to be negligible. Figure 3 shows the comparison of measured ASI's with the MASTER simulation results. Figure 4 is one of the detailed figures of Figure 3 showing the core transient induced by insertion and withdrawal of control rods is traced in a fairly well agreement. Figure 5 is another detailed figure of Figure 3 where xenon oscillation test was made. The figure shows that ASI oscillation induced by xenon is traced very well by MASTER.

4. Conclusions and Future Works

A simulation calculation was made to verify the xenon dynamics module in MASTER. The results showed that the MASTER can trace and predict xenon behavior with accuracy under any core transient state and therefore can simulate load follow operations.

In the future more simulation calculations should be made under such a transient as rapid power changes.

5. References

[1] B.O. Cho, C. H. Lee, C. O. Park, C. C. Lee, "MASTER - An Indigenous Nuclear Design Code of KAERI", Proceedings of the Korean Nuclear Society Spring Meeting Cheju, Korea, May 1996.

[2] "Functional Design Requirements for a COLSS for Yonggwang Nuclear Units 3 & 4", CE-NPSD-423-P Rev 01-P (1988.12).

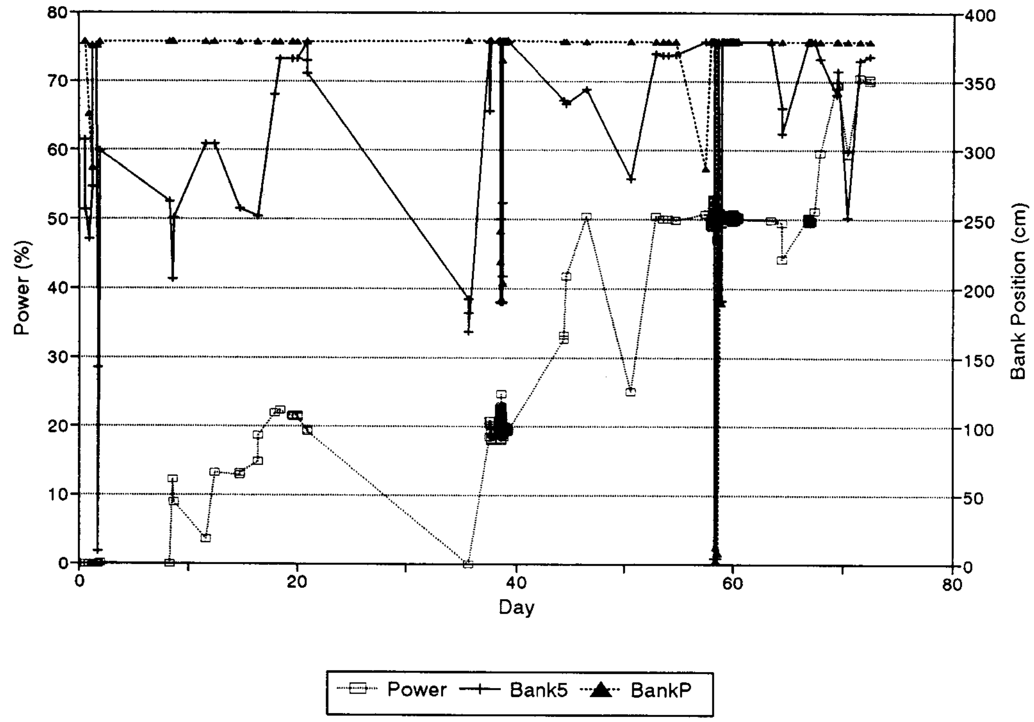

Figure 1. Operational History of YG-3, CY-1 (10/20/94 ~ 12/31/94)

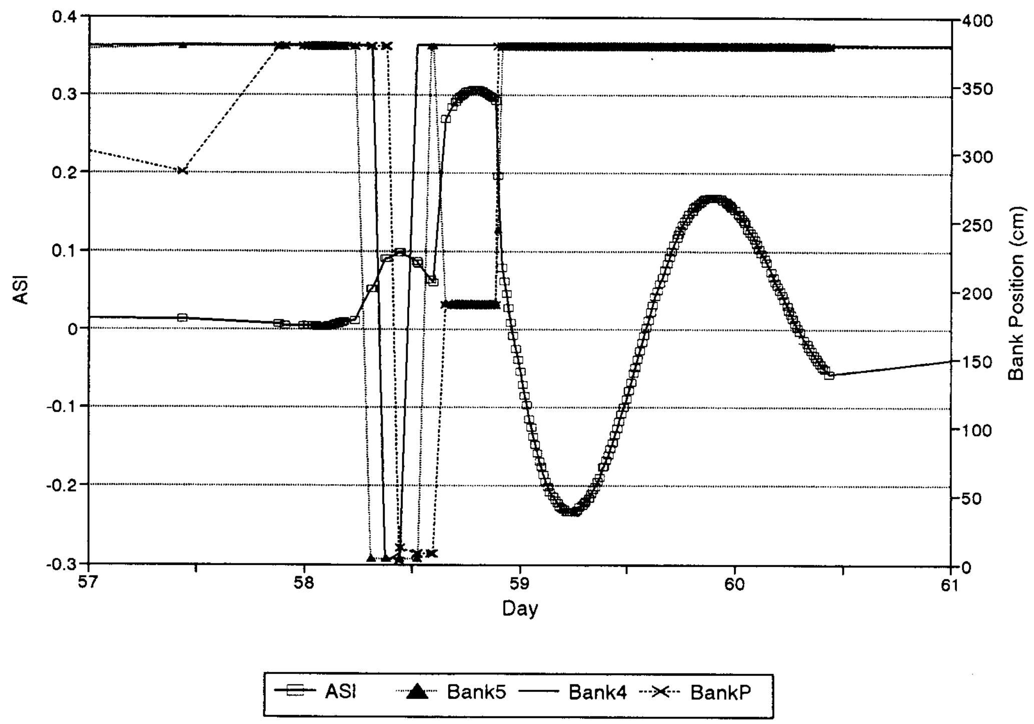

Figure 2. Xe Oscillation Test of YG-3 CY-1

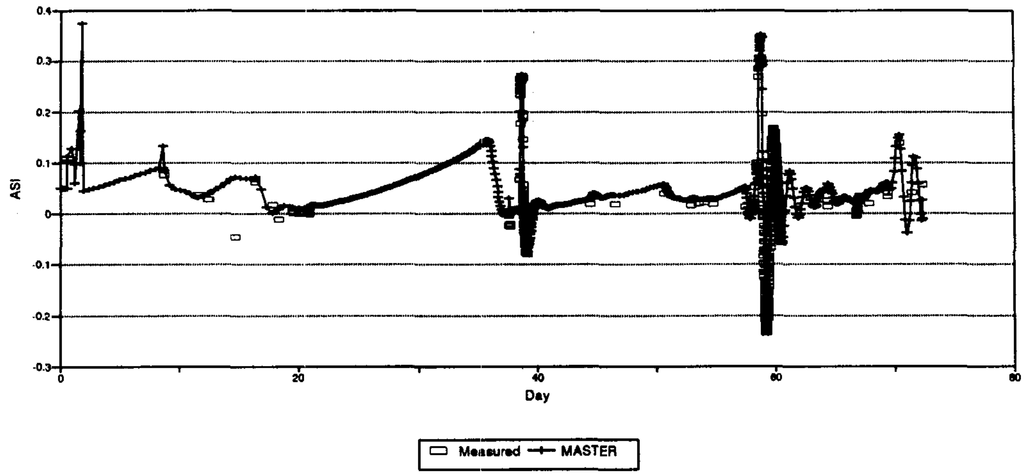

Figure 3. Axial Offset of YG-3 CY-1 (10/20/94 ~ 12/31/94)

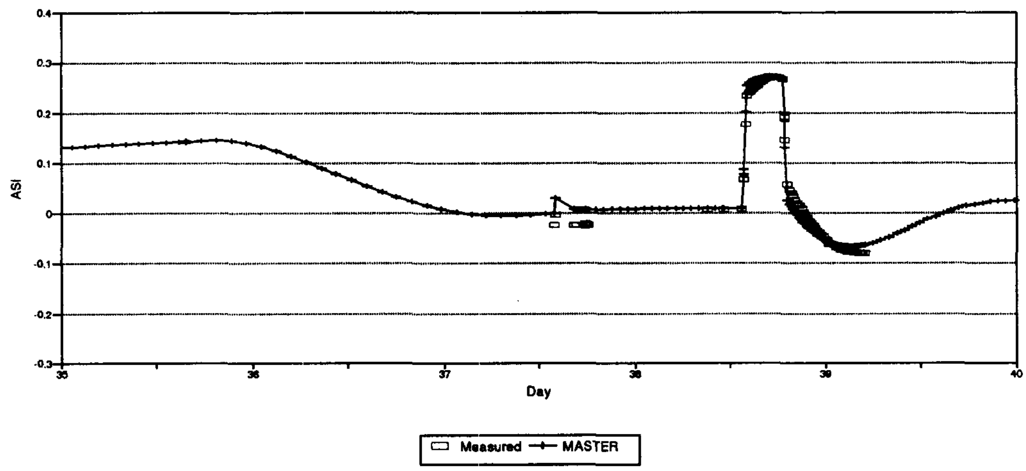

Figure 4. Axial Offset of YG-3 CY-1 (11/20/94 ~ 11/24/94)

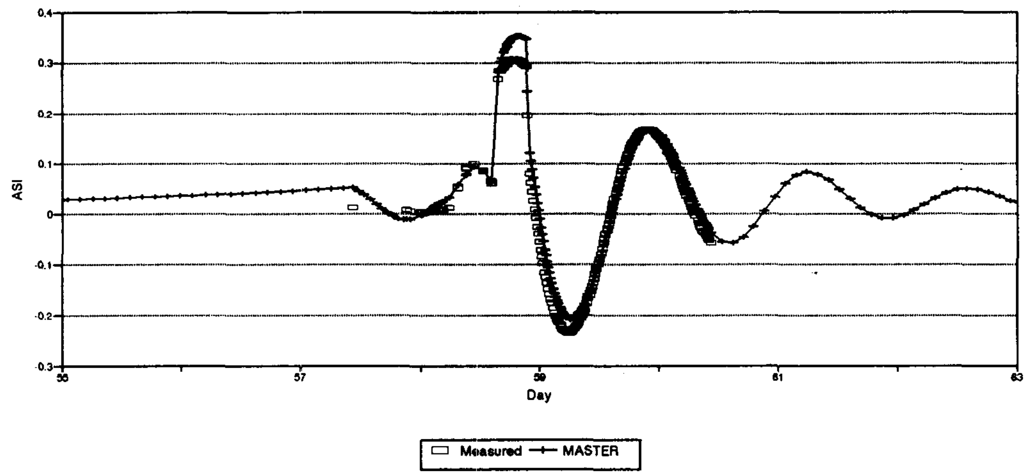

Figure 5. Axial Offset of YG-3 CY-1 (12/16/94 ~ 12/19/94)