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# Development of Reactivity Calculation Code for HANARO

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## 1. Introduction

An important part of the stable management of research reactor is the ability to identify the current status of the reactor based on statics and dynamics. In HANARO, reactor power is continuously monitored by six fission chambers mounted on the courtside wall of the reflector tank in the pool. Three of the fission chambers are used for power control, while the others are used to trip the reactor in abnormal conditions. Meanwhile, reactivity of the reactor core is measured by a multi-channel wide range reactivity computer (or called reactivity meter), which uses current signals from the compensated ion chamber (CIC) mounted on the courtside wall of the reflector tank in the pool [1]. Because there were a few difficulties in operating the reactivity meter in the MS-DOS environment, some researches have been carried out to improve and upgrade it on the Windows environment [2].

Nevertheless, it is still hard for reactor operators to immediately check the time-dependent reactivity in case of power excursion because of some limitations such as aging of devices and compatibility issues. In this study, a simple off-line tool which can estimate the time-dependent reactivity by using the fission chamber signals has been developed, and utilized to the case of loose parts of dummy rod in the 86-2th cycles of HANARO.

## 2. Methods and Results

### 2.1 Inverse Kinetic Equations

It is well known that there are several methods to predict reactivity of the reactor core. In the reactor dynamics such as asymptotic period method, rod drop/jerk method, and pile oscillator method, the reactivity or changes in reactivity is inferred from the time-dependent changes in neutron flux. For the reactivity computer, a more commonly used method involves perturbation techniques in which inverse kinetic equations are used to derive values of time-dependent reactivity from measured time-dependent neutron fluxes.

From the point reactor kinetics equations with average one-group of delayed neutrons [3], time-dependent reactivity can be estimated by using the reactor power at time *t*. The time-dependent inverse kinetic equations, with 6-group that has a decay constant $\lambda$ are defined as

$$\rho_{\$}(t) = \frac{\Lambda}{\beta}\alpha(t) + \sum_{k=1}^{6}\frac{\beta_k}{\beta}I_k(t) \tag{1}$$

$$\alpha(t) = \frac{\dot{p}(t)}{p(t)} \tag{2}$$

$$I_k(t) = \frac{1}{p(t)}\int_{-\infty}^{t}\dot{p}(t')e^{-\lambda_k(t-t')}dt' \tag{3}$$

where $p(t)$ is the time-dependent neutron power of the reactor, $\rho_{\$}(t)$ is the time-dependent reactivity function in dollar unit, $I_k(t)$ is the average density of the delayed neutron group $k$, $\alpha(t)$ is the relative change rate, $\beta$ is the fraction of delayed neutron of $k$-group precursor, $\Lambda$ is the mean neutron generation time and $t$ is time. In these equations, the source term is assumed to be negligible. Since the reactor power is measured and recorded on a reactor control computer every $\Delta t$, $\rho_{\$}(t)$ can be obtained by numerical integrations of Eqs. (2) and (3).

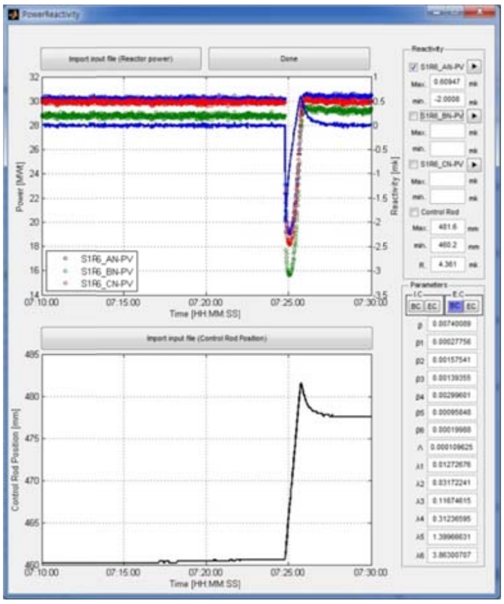
### 2.2 Development of Calculation Code

A simple code has been developed for calculation of time-dependent reactivity by using the inverse kinetic equations. The main routine was developed in MATLAB language to provide a graphic user interface and to run in the MS-Windows system. The main functions are importing power records that contain signals from three fission chambers of the reactor protection system (RPS), display reactor power and control rod position versus time, input kinetic parameters of initial and equilibrium core, and calculation of the time-dependent reactivity. Additionally, the control rod worth can be applied to determine the final reactivity value. A differential control rod worth was estimated by polynomial fitting the data from VENTURE code, as follows:

$$\begin{aligned}\rho(z) = &-0.098 + 0.066z + 0.017z^2 - (8.79E-4)z^3 \\ &+(1.45\mathrm{E}-5)z^4 - (8.02E-8)z^5\end{aligned} \tag{4}$$

where $\rho(z)$ is the differential rod worth [mk/cm], and z is the control rod withdrawal [cm].

Thermal-hydraulics and its feedback effects were not considered to the inverse point kinetics equations in the code. Because the average temperature of fuel and coolant of HANARO are about 40 and 100 °C, respectively, the fuel and coolant temperature coefficients very small [4]. However, for the reliable evaluation, the point kinetics model with reactivity feedback effects will be implemented in a fully coupled fashion in the future. The main window of the HANARO reactivity calculation code is shown in Figure 1.



☑ S1R6_AN-PV ▶
Max. 0.60947 mk
min. -2.0006 mk
☐ S1R6_BN-PV ▶
Max. mk
min. mk
☐ S1R6_CN-PV ▶
Max. mk
min. mk
☐ Control Rod
Max. 481.6 mm
min. 460.2 mm
R. 4.361 mk

β 0.00740089
β1 0.00027756
β2 0.00157541
β3 0.00139355
β4 0.00299601
β5 0.00095848
β6 0.00019968
Λ 0.000109625
λ1 0.01272676
λ2 0.03172241
λ3 0.11674615
λ4 0.31236595
λ5 1.39966631
λ6 3.86300707

Fig. 1. Main window of the HANARO reactivity calculation code

*2.3 Utilization of the Code*

Developed code was utilized to calculate the reactivity for the case of loose parts of the dummy rod in the 86-2th cycles of HANARO. In this case, the aluminum dummy material left from the IR1 hole during operation of 30 MW power. At the moment of the left, variation of the reactor power was measured by RPS fission chambers of channels A, B, and C as shown in Figure 2. The reactor power dropped sharply to about 18 MW for 18 seconds, and recovered to 30 MW by movement of the control rods. When the aluminum dummy left from the IR1 hole, the IR1 hole was filled with water. Since the change of material in the IR1 hole from aluminum to water give quick and small negative reactivity insertion, the reactor power dropped.

The time-dependent reactivity was calculated for the case of Figure 2 by using the developed code. Among three channels of the fission chambers, the power signal of channel C which was the median value was used for the calculation. The calculated time-dependent reactivity corresponding with the power is shown in Figure 3. From the result, about -2.3 mk reactivity was inserted to the core when the aluminum dummy material left from the IR1 hole. At the time, control rods moved from 46 cm to 47.7 cm from the bottom of fuels, and this control rod withdrawal corresponds to 2.6 mk considering the control rod worth.

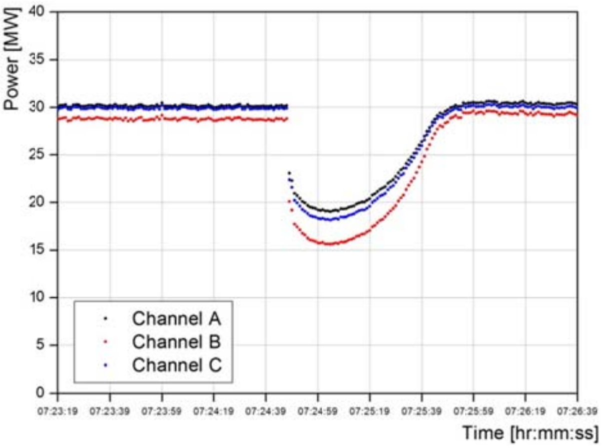


Fig. 2. Time-dependent power signals of the RPS fission chambers of channels A, B and C at the HANARO reactor protection system.

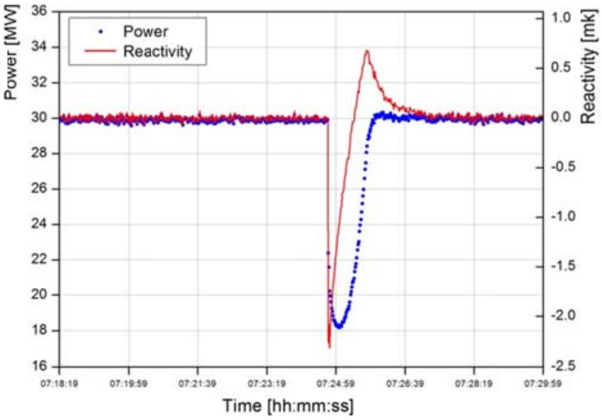


Fig. 3. Estimated time-dependent reactivity for the case of loose parts of dummy rod.

## 3. Conclusions

The main goal of this study is to produce a fast, user-friendly and interactive graphical tool for calculation of the time-dependent reactivity based on the power signals. In order to check the reactivity quickly for reactor operators, the inverse kinetic equations have been incorporated, and several useful functions have been implemented to the code. In the case of 86-2th cycles of HANARO, the developed code showed good performance to estimate time-dependent reactivity.

In the future, the on-line analysis modules will be implanted to the code with upgrade of the measurement equipment such as current meters and data acquisition devices. Additionally, reactivity will be estimated by using the reactivity meter in the MS-DOS environment, and the new Windows version, for the verification of the developed code. Because the CIC was not operated for the case of 86-2th cycles of HANARO, appropriate case will be determined, and results of two codes will be compared.

## REFERENCES

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