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Development of Advanced Digital Reactivity Computer System

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1. Introduction

The Reactivity calculator is an essential device for calculating the reactivity of the core during the zero power physics test of the reactor at the light-water reactor plant every cycle. The Reactivity calculator measures the neutron flux signal of the ex-core nuclear instrumentation system and uses flux signal as input of the inverse point kinetic equation. The validity of the nuclear design results is confirmed by comparing the measured reactivity value with the design reactivity value. Ex-core nuclear instrument of Westinghouse and OPR1000 plants is uncompensated ion chamber(UIC) and the nuclear plants have a various level of background and point of adding heat(POAH). Because the control rod worth is measured by the dynamic control rod worth measurement(DCRM) method, it is somewhat difficult to accurately measure the reactivity due to the detector noise at the low power. So, advanced digital reactivity computer system(ADRCS) was developed to calculate accurate reactivity.

2. Reactivity Calculation Methods

The point kinetic equations, describing the time evolution of reactor power for a desired reactivity insertion, ρ is given as

$$\frac{dn}{dt} = \frac{\rho - \beta}{\Lambda} n + \sum_i \lambda_i C_i(t) + S \quad \text{------------------------------ (1)}$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} n - \lambda_i C_i(t) \quad \text{------------------------- (2)}$$

Where, n(t): neutron flux density
β_i: i group delayed neutron fraction
λ_i : i group effective decay constant
$C_i(t)$: delayed neutron i group precursor density
Λ: prompt neutron generation time
ρ: reactivity
S = source strength

The reactivity ρ (t) necessary for causing the desired power transient n(t) can be obtained from the inverse point kinetics equation as

$$\rho(t_j) = \frac{\Lambda}{n(t_j)}\frac{dn}{dt} + \beta - \frac{\Lambda}{n(t_j)}\sum_{i=1}^{6}\lambda_i C_i(t_j) - \frac{\Lambda}{n(t_j)} S \quad \text{- (3)}$$

3. H/W and S/W Requirements of ADRCS

The design requirements of the reactivity calculator are accuracy, reliability, diagnosis, and measurability of dynamic control rod worth.

3.1 Hardware Requirements of ADRCS

A converter is a device that converts micro current signals input from a neutron detector into voltage signals, and the input current shall be measurable from 1 nAmp to 1,000 nAmp. The A/D converter shall be capable of high resolution and high speed sampling function in order to acquire and digitize the voltage signal output from the I-V converter at high speed. The signal resolution and sampling rate of A/D converter shall be 24 bit and 50 kS/s at least.

3.2 Software Requirements of ADRCS

The software for the reactivity calculator consist of software for measurement, analysis and verification and the software is compatible with window10 operating system and shall be consisted of a GUI that satisfies 1,920Ｘ1,080 resolution.

4. Development of ADRCS

4.1 Analysis of Background and POAH Level

Maximum and minimum values of background and POAH level were analyzed from the experience data of zero power reactor physics test. Overall, the background and POAH level of WH type plant were identified as lower power level than those of OPR1000 type plant.

4.2 Problems of Existing Reactivity Calculator

Reactivity calculation of the reactivity calculator must be performed within one second from I-V converter to A/D converter. But, existing electrometer of DDRCS(Direct Digital Reactivity Computer System) has limitations in data acquisition due to long reading time. Therefore, the accuracy of the reactivity measurement may be lowered due to the short measurement time. To improve the problems of the existing reactivity calculator, only the IV function of the electrometer was used and the function of analog/digital conversion was configured as a separate device.

4.3 Ex-core Detector Noise Removal

Gamma-ray background signals and electrical noise signals from cables and measurement systems around of UIC ex-core detector are sources of noise. A noise filter was applied to remove signal noise of ex-core detector and A/C power.

4.4 Performance Test of ADRCS

Signal linearity and reactivity perturbation levels were evaluated for various devices selected as current-voltage converters to select improved reactivity calculator devices. Performance test was carried out in Kyung Hee University Research Reactor (AGN-201K).

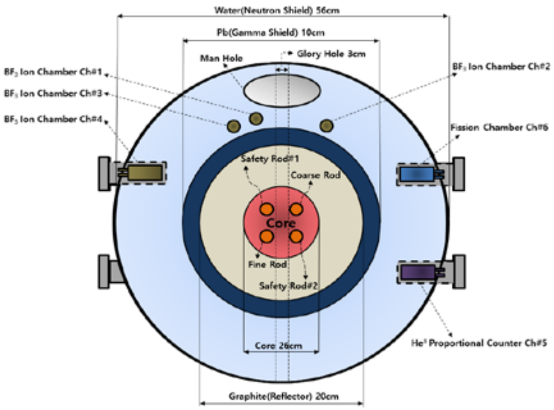

Fig. 1. AGN-201K Research Reactor

In order to evaluate the performance of ADRCS, the test section was selected as a low-power and high-power section. The reactivity perturbation, linearity of the measurement signal were selected as test items by varying the power of the core in each test section. When evaluating the performance of each device after the test, it was compared and evaluated by referring to the coefficient of measurement and reactivity of the fission chamber and He-3 detector. Also, it was verified whether the reactivity was not continuous on the ADRCS power range change. The results of the reactivity perturbation test were evaluated that the ADRCS method decreased the reactivity perturbation by about 2.5 times or more compared to the DDRCS method. It is analyzed that the measurement error by high-speed sampling of ADRCS decreased, resulting in decrease in response perturbation. As a result of the signal linearity test, the ADRCS-type Keithley 6485 product was evaluated to be the best in the low-power section dynamic test and the full-power section static test.

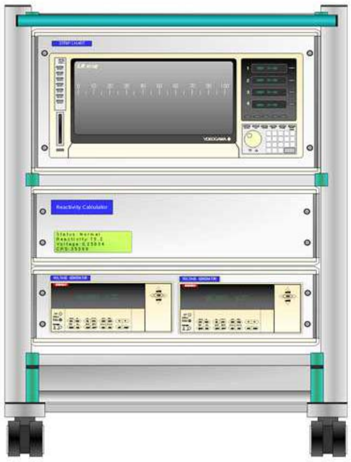

Fig. 2. Appearance of ADRCS

5. Conclusions

Overall, the ADRCS Keithley 6485 device showed excellent results in terms of signal linearity, response perturbation, and durability of the device, and was evaluated as the most suitable device for the improved response calculator device. It will be applied to actual physics test after verifying of performance using ADRCS developed during the zero power reactor physics test.

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