Current Status and Future Works in Dynamic Control Rod Worth Measurement Method in KOREA

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1. Introduction

The DCRM(Dynamic Control rod Reactivity Measurement) method [1,2] with automatic background signal compensation technique was developed by KEPRI in 2003 and officially approved by the regulatory body in 2006 in KOREA. Now this method used for all of PWRs in KOREA to measure the control rod (actually bank) worth during the low power physics tests. Actually all ex-core detector signal data processing and extracting the final conclusion about the single control bank was performed by the 3rd generation of Digital Reactivity Computer System (DRCS). From 2006 to 2016, about 250 control bank worths were measured and the difference between measured and calculated worth of individual bank were several % and total rod worth differences of each cycle were less than 3%. However there were a few odd cases showing the individual difference greater than 15% which is the criteria. And some OPR1000 nuclear power plants built recently use fission chambers instead of traditional uncompensated ion chambers. To consider those conditions, any modification of the DCRM method and DRCS were requested. In this paper, short description about DCRM method, current status of DCRM modification and future works are discussed.

2. Methods

Compared with other rod worth measurement methods, the DCRM method uses very simple behavior; just a single bank's insertion and withdrawal with full speed. (See Fig. 1 [1]) The reactivity change during rod movement is determined by the point kinetics equation with ex-core detector signals (which turns out as core-averaged neutron density variation) and pre-calculated core-averaged dynamic parameters such as decay constants of precursor groups;

$$\rho(t_n) = \sum_k \beta_k \left(e^{-(\lambda_k+\omega_n)\Delta t_n} B_{n-1,k} + A_{n,k} \right) + \Lambda\omega_n - \bar{S}_0 \frac{\Lambda}{\bar{n}_n}, \quad (1)$$

where

$$\bar{n}_{n+1} = \bar{n}_n \cdot e^{\omega_n(t_{n+1}-t_n)}, \; B_{n,k} = e^{-(\lambda_k+\omega_n)\Delta t_n} B_{n-1,k} + A_{n,k},$$

$$A_{n,k} = \frac{\omega_n}{\lambda_k+\omega_n}\left(1 - e^{-(\lambda_k+\omega_n)\Delta t_n}\right), \text{ and } \Delta t_n = t_{n+1} - t_n.$$

However, the final results should be the static worth to compare with designed value in Nuclear Design Report and the static worth can not be the solution of Equation (1) because it gives the dynamic worth. Therefore, several factors such as Dynamic to Static Conversion Factor (DSCF) and Neutron-to-detector Response Conversion Factor (NRCF) were developed to get the final static reactivity.

The overall data generation process (0 stage and blue characters) and measurement process (from 1 stage to 5 stage and black characters) of the DCRM method was described in Fig. 2.[1] At stage 0, MAKECXFILE, RAST-K and INVERSE code system [1] were used. MAKECXFILE generates cross-section data set for RAST-K code from the specific nuclear design code outputs. RAST-K code is used for the simulation of excore detector behavior during rod movements of all control banks to be measured. And INVERSE code generates DSCF and NRCFs at each control rod insertion position. At stage 4 and 5, INVESE code used once again for the calculation of the measured dynamic and static control rod worth at each control bank insertion position based on the pre-determined DSCF and NRCFs. Figure 3 [1] shows a typical measured rod worth provide by INVERSE code.

The original DCRM method had developed the background signal compensation method because UIC(uncompensated ion chamber with Boron coated) signals are contaminated by Gamma-rays around the detector. [1]

average event rate of 10 8 events/s.

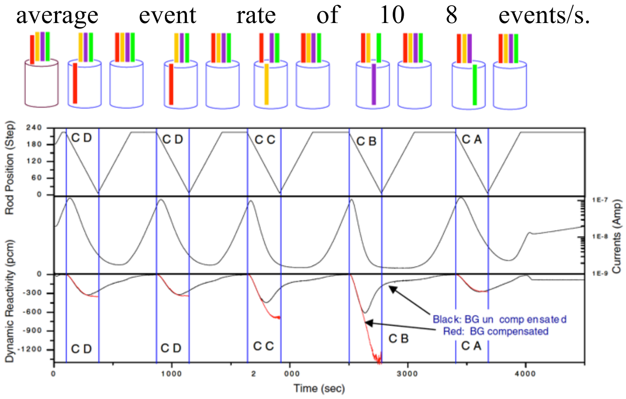

Fig. 1. Example of the DCRM process

In DCRM method, a control bank moves in a reactor with full speed such as 30 step/min. Measured detector signals decreases up to 1/1000 (three decades) when it hit the bottom of the core. Therefore the data acquisition system has to measure a specific ex-core signal without delay effect during almost three decades. The original DRCS measured the current signals provided by UIC chamber through high performance electrometers for each top, middle and bottom detector.

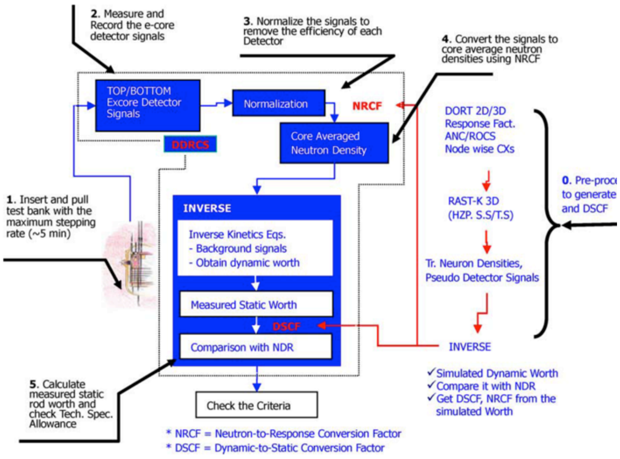

Fig. 2. Overall Data process in the DCRM method

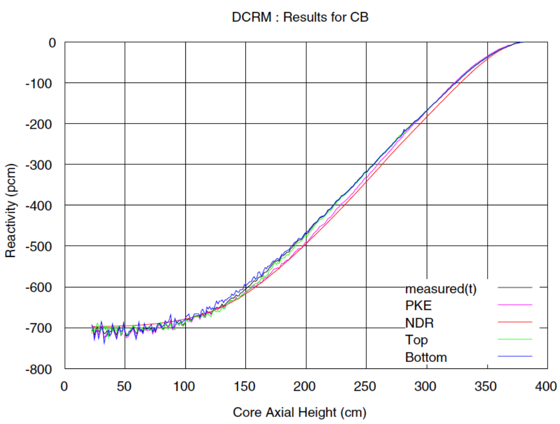

Fig. 3. Typical output of the DCRM process

3. Modified DCRM Method

However, the original DCRM method does not work in case of the OPR1000 and APR1400 reactors where the fission chambers (FCs) are installed as ex-core detectors. Because FC uses pulses generated by an interaction between neutron and U-235 (>95%) coated on the electrode, FC shows good resolution without Gamma-ray effects, good linearity with neutron intensity, and long-life time (~ 40years) compared with UIC's operational time (~10years). Although FC is a good measurement device during normal operation of from source range to power range, FC has also disadvantage during the zero power physics test, especially control rod measurement test. When a control rod hit the bottom, the neutron count rates decrease up to several hundred cps. In this area, the fission reactions in FC are governed by probability so that the count rates vary with time even at the constant power level. It means that there are large reactivity fluctuations. And there is no Gamma-ray effect on signals. It means no background compensation algorithm required. Therefore, for PWRs with fission chamber as ex-core detector, a modified DCRM method including INVERSE-FC, MAKECXFILE and RAST-K code, and new reactivity computer system were developed where neutron pulse signals from all ex-core detectors are used. Fig. 4 shows the measured static rod worth of regulation bank four of 881 pcm. Modified DCRM method works for those PWR LPPT with FCs.

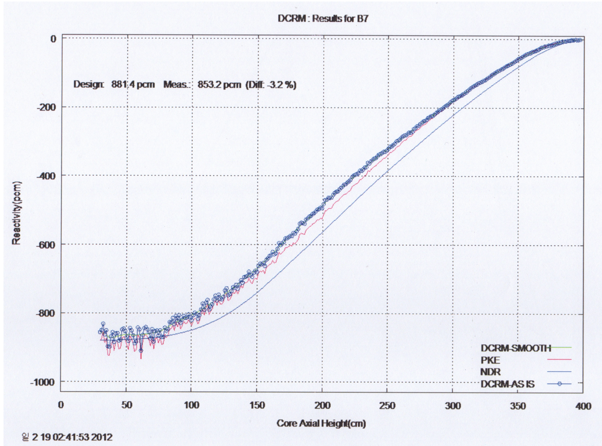

Fig. 4. Example results using modified DCRM method

However there is a disadvantage of using neutron pulse; linearity broken to power level after specific count rate. In this case, LPPT test range can be reduced and maybe it is very difficult to check other parameters such as critical boron concentration, Isothermal Coefficient, and Moderator Temperature Coefficient.

4. Odd results

About 10 cases among about 250 control bank worth measurement with original DCRM method with UIC signals result in very heavy fluctuation on reactivity curve and the difference approaches 15%, the individual limit. The electrometer signals processing method were the main cause. To overcome this problem, a modified reactivity computer system using own current treatment logic was designed. It shows the reactivity fluctuation can be reduced dramatically in case of UIC signal.

Recently the modified DRCS coupled INVESE code applied Westinghouse 2 Loop plant and gave very good results except a control bank whose measured rod worth was shown of 18% difference from the estimated value. The results were same for three repeat tests. All possible causes are examined from computer codes to detail data acquisition system. The remain factors to be checked are the detector response factor from DORT code and the twisting or thinning of shroud or barrel by aging.

5. Further works

The DCRM method has changed completely the LPPT procedure; it saves more than 10 hours of testing time, reduces human error and boron waste dramatically, and diminishes tester's burden. It can be modified easily without any harm on the method's core part according to the plant status, especially ex-core detector's geometry and characteristics. And those modifications work well and solve the DCRM's problems. The solution for the recent observed odd case will be found and it makes more concrete DCRM techniques.

REFERENCES

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