Preliminary Analysis of Dynamic Control Rod Reactivity Measurement Method for Fission Chamber Excore Detector

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1. Introduction

The rod worth measurement is one of essential tests in the low power physics test (LPPT) program of the commercial pressurized water reactors (PWRs). The consistency between the predicted rod worth and the measured rod worth can ensure the safety margin for the reactor shutdown and check the power distributions to prevent the possible fuel misloading condition before the power ascension.

The traditional rod worth measurement method measures the cumulative reactivity by the boron dilution or the reference bank withdrawal during the test bank insertion to maintain the reactor core near the critical state. Thus, the traditional method produces a huge amount of radioactive liquid waste and takes a very long test time (8~12 hours). To overcome this problem, the dynamic control rod reactivity measurement (DCRM) method was developed ([1,2]) and licensed in 2006. The DCRM method measures the ex-core detector signal during the test bank insertion without any additional reactivity changes to the reactor core. Thus, it does not need any change in the soluble boron concentration for the rod worth measurement and the test time becomes less than three hours. The DCRM method has been applied to the PWRs in Korea since 2006.

The DCRM method was originally developed to utilize the current signal of an ex-core detector such as an uncompensated ion chamber (UIC). However, the application of the DCRM method has been restricted for several PWRs equipped with integrated wide-range fission chambers (FC) due to the relatively low neutron sensitivity [3].

In this paper, a new DCRM procedure for the wide-range FC is presented. The new method, named as DCRM-EK, utilizes the pulse mode of the FC, where the measurement procedure is modified to maximize the linear test range of the pulse mode. A preliminary analysis shows a promising performance of the DCRM-EK method.

2. Framework of DCRM Method

The overall framework of the DCRM method is shown in Figure 1. The DCRM method consists of the pre-calculation stage and the measurement stage. As a first step of the pre-calculation, the neutron transport calculation for the core-detector geometry is performed to calculate the detector response function (DRF). Usually, the DRF is obtained by the synthesis of the two adjoint flux distributions from the RZ and RΘ geometries for the computational efficiency. Second, the lattice physics calculation for the fuel assembly geometry is performed to generate two-group constants and the delayed neutron data. Third, the static and the transient nodal diffusion calculations are performed for the insertion and the withdrawal of each test bank to generate the ex-core detector response conversion factor (DRCF), the point kinetics parameters, and the dynamic to static conversion factor (DSCF) [2].

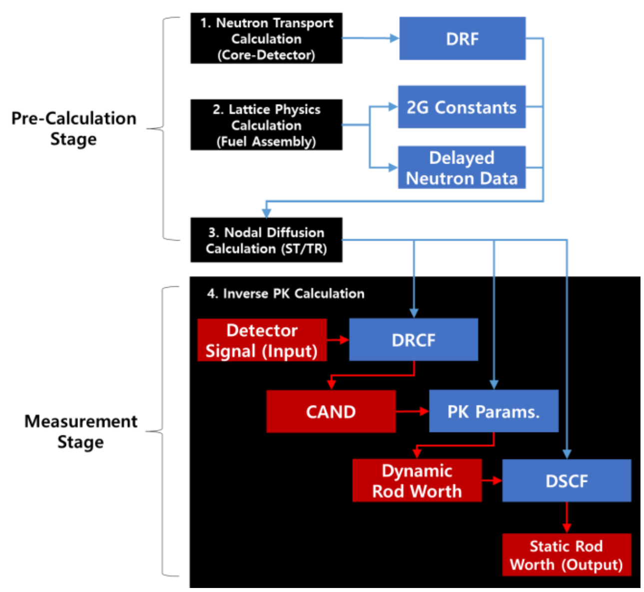

Figure 1. Overall framework of DCRM method; the blue color indicates the pre-calculation procedure while the red color indicates the measurement procedure.

In the measurement stage, the three pre-calculated parameters are used to obtain the static rod worth. First, the ex-core detector signal is converted into the core-average neutron density (CAND) by the DRCF. Then, the inverse point-kinetics calculation is performed to obtain the dynamic reactivity of the control rod. Based on the characteristics of the dynamic reactivity curve (reactivity vs. rod position), one can iteratively search for the background signal and update the dynamic rod worth. Finally, the dynamic rod worth is converted into the static rod worth by the DSCF. A more detailed description for the DCRM method can be found in Ref. [2].

3. Modified DCRM Method (DCRM-EK)

A modified DCRM method, named as DCRM-EK, is proposed to overcome the low sensitivity of the integrated wide-range FC. The overall framework of the DCRM-EK method has not been changed from

Figure 1. However, the new method utilizes the pulse mode of the fission chamber, where the measurement procedure is modified to maximize the linear test range of the pulse mode. The pulse signal of the FC is not contaminated by the background gamma-ray so that the background signal compensation algorithm is not required. Figure 2 illustrates the modified measurement procedure of the DCRM-EK. Since the core condition during the DCRM-EK procedure changes from equilibrium (or critical condition) to kinetics (or transient) status, 'EK' means 'Equilibrium to Kinetics'.

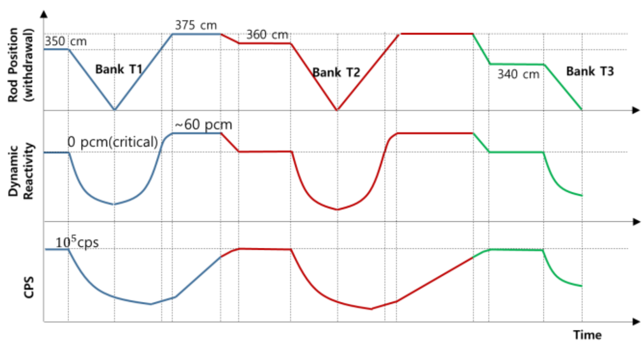

Figure 2. Measurement procedure of DCRM-EK.

4. Numerical Results

Although there is a lack of data measured from commercial reactors as it is in the development stage, there is one meaningful test data obtained from a PWR in Korea. Figure 3 shows integral rod worth curves for a typical control rod bank measured via the DCRM-EK method. One can see a good agreement between the measured static rod worth and the designed rod worth from the Nuclear Design Report (NDR). The difference between the measured static rod worth and the NDR rod worth is -1.8%, which sufficiently satisfies the test acceptance criteria.

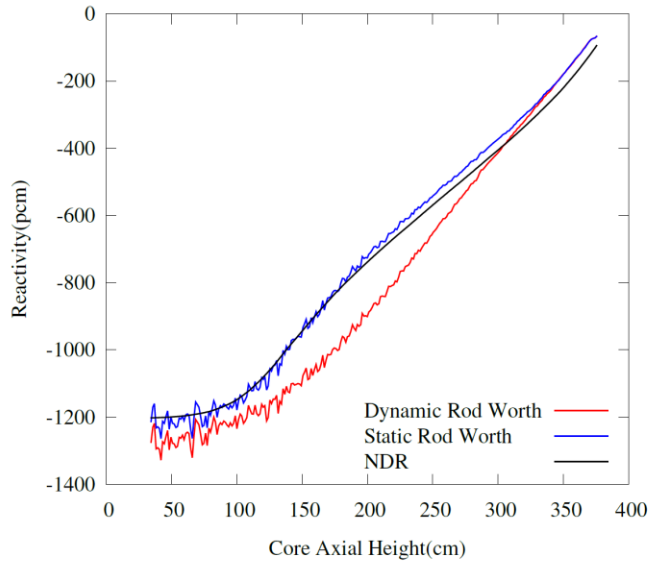

Figure 3. Measured integral rod worth (blue line) by DCRM-EK method.

5. Summary and Further Work

The DCRM-EK method has been proposed for the pulse-mode of the wide-range FC. The very preliminary analysis shows a promising result. Once sufficient measured data (about 30 rod worth cases) has been obtained, the DCRM-EK can be applied to PWRs in KOREA. In addition, it will also be applicable even if the signal noise is large so that it is difficult to estimate appropriate rod worth by the original DCRM method.

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