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Evaluation of Pulse Signal Normalization of Reactivity Measurement using Fission Chamber Ex-Core Detector

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1. Introduction

PWRs commonly perform the Low Power Physics Test (LPPT) at the beginning of the startup to verify the safety and reliability each cycle nuclear design [1]. One of LPPT is the rod worth measurement test, and this test is most important one. For rod worth measurement, we use the ex-core detector signal to calculate the reactivity when control rods are inserted or withdrawal.

Some PWRs uses pulse signal of Fission Chamber Ex-core detector for LPPT [2]. The pulse signal has its characteristics and it affects the way to measure the reactivity.

In this paper, the reactivity measurement using fission chamber is evaluated, especially for the control rod worth measurement.

2. Methods and Results

2.1 Characteristics of Pulse Signal of Fission Chamber

Fission Chamber of Ex-Core detector measure leakage neutron from reactor core and normally generates the three types of signals. They are pulse signal, MSV (Mean Square Voltage), and current signal. Especially, pulse signal usually utilizes for startup and low power ranges because pulse signal count starts to saturate at the specific pulse count rate. When pulse counts go over the saturate point, pulse signals are saturated. After that, linearity of signal is broken and less reactivity is calculated against real reactivity as shown in Figure 1.

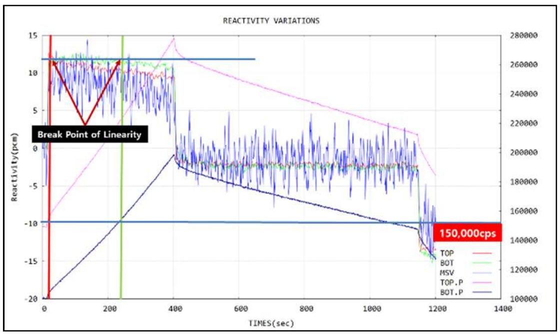

Fig. 1 Pulse Signal Saturation and Distortion of Reactivity

2.2 Reactivity Calculation

When we measure the control rod worth or other reactivities during the LPPT, Reactivity computer calculates each reactivity using ex-core detector signals.

Generally, eight or twelve ex-core signals are connected to the reactivity computer and reactivity computer uses arithmetic mean of all detector signals as shown in follows,

$$S = \frac{S_n^{Ch.A,Top} + S_n^{Ch.A,Mid} + S_n^{Ch.A,Bot} + \cdots + S_n^{Ch.D,Bot} + \cdots}{N} \quad (1)$$

S is the arithmetic mean of the N detectors, it is represented of neutron population in reactor core. Therefore, △S is used as △n for calculation in Inverse Pointe Kinetic Equation.

However, this arithmetic mean value has a problem for the pulse count detector case. If one detector has a very big count rate compared to others, this detector affects most of calculation against others.

If bottom detector of channel D is huge, reactivity will be calculated as follows,

$$w_n = ln\frac{S_{n+1}}{S_n} = ln\left(\frac{S_{n+1}^{Ch.A,T} + S_{n+1}^{Ch.A,M} + \cdots S_{n+1}^{Ch.D,B}}{S_n^{Ch.A,T} + S_n^{Ch.A,M} + \cdots S_n^{Ch.D,B}}\right)$$
$$\cong \ln\left(\frac{S_{n+1}^{Ch.D,B}}{S_n^{Ch.D,B}}\right) (2)$$

This means one detector which has big count rate is dominant effect for reactivity calculation and especially, if that signal is pulse count, it should be concerned for reactivity calculation.

Figure 2 shows the rod worth measurement example case for this concern. These measurements are performed by the boron dilution method to measure a reference control rod worth.

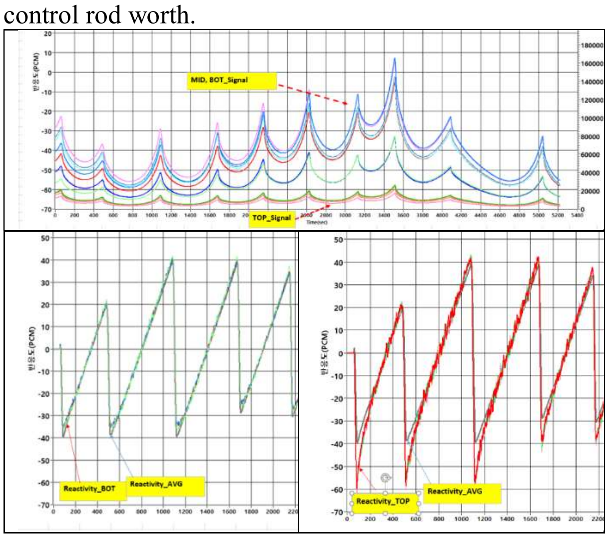

Fig. 2 Reactivity Calculation for Each Detectors

Positive reactivities inserted to the reactor core due to the dilution of coolant and its reactivities are swapped by insertion of reference control rod.

As shown in Figure 2, middle and bottom detector have bigger signal rate compared with Top detector signal. And reactivity which calculated by arithmetic mean shows similar trend with reactivities of middle and bottom detector, and the reactivity of top detector shows bigger reactivity. That is the same characteristic of pulse signal mentioned above. Some of pulse signal from middle and bottom detectors are over the saturation point, then the reactivity calculates less than the one of top detector.

2.3 Pulse Signal Normalization

In order to avoid the bias and distortion of reactivity calculation, pulse signal normalization is suggested and implemented to reactivity computer. All detector signals are normalized by each average detector signal count rates as follows,

$$\overline{S_n^{Ch.X\,Y}} = \frac{S_n^{Ch.X\,Y}}{S_{avg}^{Ch.X\,Y}}, \qquad \text{where } S_{avg}^{ChX\,Y} = \frac{\sum_{n=1}^{N} S_n^{ChX\,Y}}{N} \quad (3)$$

Through each channel normalization, the mean value is the almost same as below.

$$\overline{S_n^{Ch.A\,Top}} \cong \overline{S_n^{Ch.A\,Mid}} \cong \overline{S_n^{Ch.A\,Bot}} \cdots \cong \overline{S_n^{Ch.D\,Bot}} \quad (4)$$

The effect from the specific detector which has big count rate is removed, therefore, the cause of reactivity calculation distortion is also deleted.

2.4 Evaluation

In order to evaluate the effect of the normalization, the above equation (3) and (4) of pulse signal normalization is implement to the reactivity computer. There are some cases for this phenomenon. Nuclear design of some plants is utilized for Less Low Leakage Loading Pattern. this loading pattern makes the more neutron leakage and some detectors are over-detected beyond the saturation point. Figure 3 shows the control rod measurement cases where equation 4) is applied and compared with Figure 2. Each measurement of reactivity is calculated by reactivity computer directly.

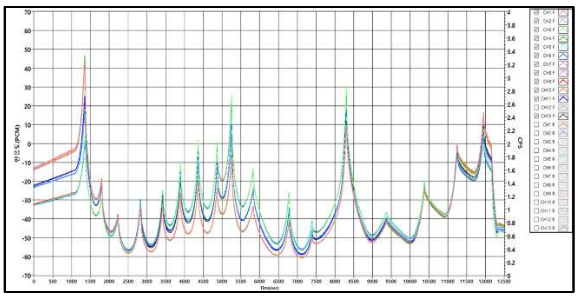

Fig. 3 Normalized Pulse Signal of Each Detectors

Figure 4 and Table 1 shows the comparison of the result between non-normalization and normalization. Pulse signal normalization is affected to increase each measured reactivity. Since some detector's signals are over the saturation point, non-normalized signal's reactivity is under estimated.

Figure 4 and Table 1shows the reactivity differences of each steps are about 1~10 pcm, total reactivity differences are around 50~60 pcm. This is huge because the test criteria are that error should be met the between ±10%. And reference rod worth is more important, other test rod worth measurement uses the result of the reference rod worth measurement.

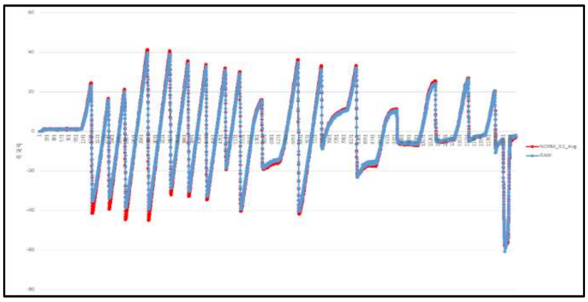

Fig. 4 Normalized Reactivity (Red Line) vs. Non-normalized Reactivity (Blue Line)

Table 1 Results of Pulse Signal Normalization

Case No.	Control Rod Worth Measurement		
	Prediction worth[pcm]	Measurement Error(%)	
		Non-normalized (%)	Normalized (%)
1	1095.2	-3.48	**+0.44**
2	1035.5	-4.04	**+1.85**
3	1184.0	-3.89	**+1.94**

3. Conclusions

In this study, pulse signal normalization of fission chamber of ex-core detector is evaluated. The fission chamber pulse signal can be saturated and it causes reactivity bias and distortion. And reactivity computer uses the arithmetic mean of ex-core detector signal, it also causes the reactivity bias of the specific detector which has much bigger count rates against others. In order to avoid this problem, pulse signal normalization is implemented to reactivity computer. Through evaluation to some cases, it shows the bias and distortion are removed. This technique can also be applied to those reactors using current signal. These updated reactivity computers which implemented equation (3) and (4) already are utilized for Korea PWRs.

REFERENCES

[1] ANSI/ANS 19.6.1, "Reload Startup Physics Tests for Pressurized Water Reactors"
[2] H.S. Lee et al., "Modification of Detector Response Function for Dynamic rod worth measurement," Transactions of Korean Nuclear Society, Oct. 2022