RCS Leak Rate Calculation with High Order Least Squares Method

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1. Introduction

As a part of action items for Application of Leak before Break(LBB), RCS Leak Rate Calculation Program is upgraded in Kori unit 3 and 4. For real time monitoring of operators, periodic calculation is needed and corresponding noise reduction scheme is used.

This kind of study was issued in Korea, so there have upgraded and used real time RCS Leak Rate Calculation Program in UCN unit 3 & 4 and YGN unit 1 & 2. For reduction of the noise in signals, Linear Regression Method was used in those programs.

Linear Regression Method is powerful method for noise reduction. But the system is not static with some alternative flow paths and this makes mixed trend patterns of input signal values. In this condition, the trend of signal and average of Linear Regression are not entirely same pattern.

In this study, high order Least squares Method is used to follow the trend of signal and the order of calculation is rearranged. The result of calculation makes reasonable trend and the procedure is physically consistence.

2. Methods and Results

2.1 High Order Least Squares Method

An Nth order polynomial to approximate a pattern is as follows:

$$y = \sum_{n=0}^{N} a_n x^n , \qquad (1)$$

where y = the real value of signal,
x = relatives of signal, in this case, time,
a_n = an nth order coefficient to be calculated.

When a set of real measured value of signal, (x_i , y_i), is applied above equation, the error of approximation, r_i, is as follows:

$$r_i = y_i - \sum_{n=0}^{N} a_n x_i^n \qquad (2)$$

When the number of measurement is M, the sum of squares of the errors of fitting curve is as follows:

$$\sum_{i=1}^{M} r_i^2 = \sum_{i=1}^{M} (y_i - \sum_{n=0}^{N} a_n x_i^n)^2 \qquad (3)$$

To get the coefficients, the equation is partial differentiated with each coefficient.

$$\frac{\partial}{\partial a_n} \sum_{i=1}^{M} r_i^2 = 2a_n \sum_{i=1}^{M} x_i^n (y_i - \sum_{n=0}^{N} a_n x_i^n) = 0 . \qquad (4)$$

Finally, the multi variable equation is simplified as follows:

$$\mathbf{Xa} = \mathbf{y} . \qquad (5)$$

Where **X** is $(N+1)\times(N+1)$ matrix with time term only, **a** is coefficient vector, and **y** is vector of time weighted measured values. The vector **a** can be calculated by inversion of the matrix **X**.

2.2 Application of Method on Mass of Components

Typically RCS leak rate is calculated from mass change of reactor coolant loop(RCL), pressurizer, and volume control tank. Because of high flow rate of RCL and pressurizer, the measured values of pressure and temperature of these components have large noise and fluctuation.

Until now, the technique of noise reduction is applied on signal inputs and pre-conditioned signal values are used to calculate the mass of components. This sequence has following problem:

(1) Leak rate is calculated with mass change of components, so we need representative values of mass.
(2) Linear regression or least squares method can make representative values and a linear calculation of the values can make a representative result.
(3) Pre-conditioned signal values are temperature, pressure, and level of tanks, but they are not linear with mass.

So, noise reduction applied on signal values makes inconsistency. In this study, this inconsistency is corrected with changing calculation order.

To get representative values of mass of each component, we calculate every mass with input signals of every time step without pre-conditioning. And the representative values of mass are calculated with those mass values by least squares method.

The resource of CPU is more consumed than former sequence because steam table program is used more frequently for the calculation of mass from temperature, pressure and tank level. But it can keep consistency.

2.3 Calculation Scheme

By Fourier analysis, the trend of all signals related with RCS leak rate is analyzed. Much resource would be consumed to apply High Order Least Squares

Method on all components, so we select critical signals to be applied the method.

The selected critical values are mass of water in RCL and mass of water in pressurizer. The trends of them are so complicated and more powerful fitting functions than linear lines from linear regression are needed.

At first, we apply new calculation scheme on mass of RCL and the change of mass and leak rate of RCL are calculated as table 1. The mass of RCL is calculated with two methods, linear regression and 5th order least squares curve from Kori unit 3 data for 3 hours in normal operation.

Table 1. The mass change of RCL

Method	linear	5th order
mass change(kg)	-5.35	5.65

Total mass of RCL is over 180 tons and the change is only 0.003%. But the change makes 0.01 gpm of leak rate and the value is 10% of limit of unidentified leak rate. In this result, we should be attention on the opposite trend of the values as well as the difference of them.

Fig. 1 shows the trend of mass of RCL and fitting functions. Calculated mass of RCL varies with several effects in normal operation, such as make-up water, power transition, heating of pressurizer water, etc. So, when one use inventory valance method to calculate RCS leak rate, more than 2 hours interval between start and end of check time is recommended. From the graph, we can find the trend of mass of RCL, noisy gray curve, is varying so frequently as with hour order, it makes uncertainty to linear regression method. The only way to use linear regression method for mass of RCL is to expand the interval to several hours so the noise term become smaller by the width of fluctuation being divided by time.

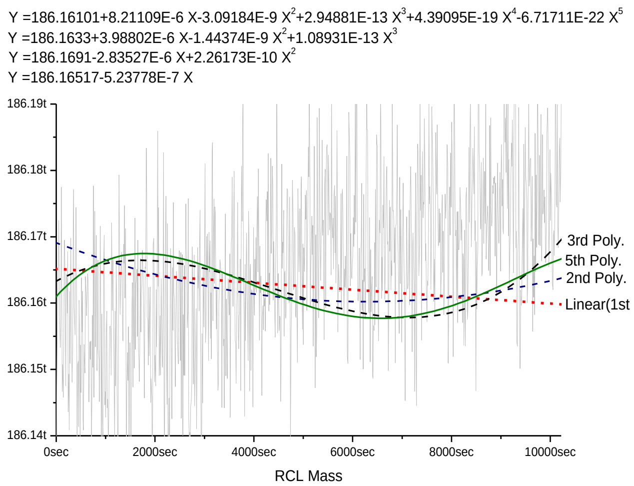

Fig. 1 The trend of mass of RCL

High order polynomial can follow the trend of mass faster than linear line so that can make more accurate solution with short interval.

2.4 Effect of Calculation Order

We calculate the change of mass with following two sequences.

(1) First, making representative signal values of start and end time, and calculating mass of those times to get mass change
(2) First, calculating mass of every time steps and making representative mass values of start and end time to get mass change

The difference of between two results is very small, under 0.001% of mass for almost every time steps. For such small temperature and/or pressure gap, specific volume of water is almost linear with temperature and/or pressure. But we can find large difference over 0.1% of mass in volume control tank when make-up is just ended. The temperature of make-up water is more than 10℃ under that of the water in VCT and the temperature of the water in VCT is cool down instantly. Now we can find the difference and we are analyzing the physical meanings.

3. Conclusions

It is shown that High Order Least Squares Method is more powerful method than Linear Regression to calculate representative mass value of RCL. We can expect more accurate solution of RCS leak rate within 2 hours interval.

We applied the method in Kori unit 3 and 4, and by analyzing of 1 cycle data, we expect another majority of this scheme can be found. It is our next job and this scheme is expected to approve RCS leak rate calculation process.

REFERENCES

[1] USNRC, NUREG-1107, Reactor Coolant System Leak Rate Determination for PWRs, Dec, 1984.
[2] Pressurized Water Reactor Owners Group Standard Process and Methods for Calculating RCS Leak Rate for Pressurized Water Reactors, WCAP-16423-NP, Sep, 2006.
[3] Pressurized Water Reactor Owners Group Standard RCS Leakage Action Levels and Response Guidelines for Pressurized Water Reactors, WCAP-16465-NP, Sep, 2006.
[4] N. L. Choi, S. K. Suh, J. H. Cho, S. J. Yune, S. J. Baik, "A Study on the Improvement of RCS Leak Rate Calculation Program", Korean Nuclear Society Autumn Meeting, 2004.
[5] Erwin Kreyszig, Advanced Engineering Mathematics, John Wiley & Sons, Inc., 1988.