Development of the Test Bed for Advanced RCS Unidentified Leakage Detection Techniques

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1. Introduction

The leakage from a RCS(Reactor Coolant System) is classified into identified leakage which is defined as leakage in to the closed system boundaries and unidentified leakage which is all other leakages.

Since the reactor operates at high temperature and pressure conditions, the unidentified leakage is released by gaseous state and its amount collected in sumps is too small to be captured. However, it has significant meaning from a viewpoint of nuclear safety.

The unidentified leakage was typically determined by the RCS inventory balance method that NUREG-1107 recommended [1]. To enhance the accuracy, and robustness of the method, a kind of filtering techniques such as linear regression has been used. However, the conventional filtering techniques did not reflect the step change in any transient conditions such as injection or discharge. In order to compensate this shortcoming, we have proposed advanced techniques such as the Kalman filter [2] and the bilateral filters [3]. This study, as an extended part of the previous research, attempted to develop the test bed which is based on the RCS inventory balance method and is able to test various filtering techniques using LabVIEW. The test bed enables to collect the data on-line/ off-line and to perform the benchmarking tests among the filtering techniques.

2. Methods and Results

2.1 Architecture of the Test Bed

The test bed is developed on the LabVIEW environment and primarily based on the algorithm of the RCS inventory method. As shown in Fig.1, the test bed is possible to be connected with data acquisition systems as well as the signal which stored in a spread sheet so that it can collect the data on-line/off-line. In this manner, we can input the values of temperatures, pressures and levels of water as input signal, and the results for leakage can be presented in the form of graphs or real numbers.

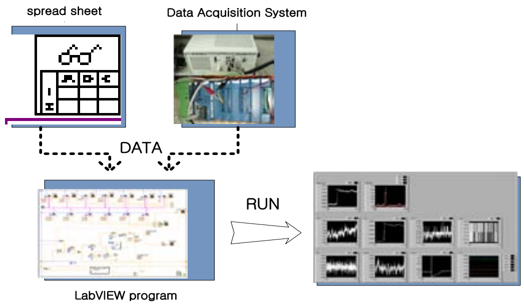

Fig. 1 Flow diagram of the test bed for the RCS unidentified leakage detection program

2.2 Analysis of Digital Filters

Not only to check the test bed but also to evaluate the performance of the various filters in improving the accuracy and robustness of the RCS inventory balance method, we widely investigated several digital filters while previous studies focused on only the Kalman filter and the bilateral filter.

Digital filters have been used to reduce the error, which is high-frequency noise, in process values. Each filter type has its own advantages, as well as associated shortcomings. Some are able to significantly reduce noise but they introduce a sizable delay in the filtered response. There are other filtering procedures that do not add a long delay but do not produce satisfactory noise removal.

We analyzed four different types of the digital filters: (1) exponential filter, (2) nonlinear exponential filter, (3) moving-average filter and (4) Polynomial filter and applied them to the test bed. Fig. 2 shows the performance of these filtering for same example which contains two step signals, steady-state noise, and a spike [4].

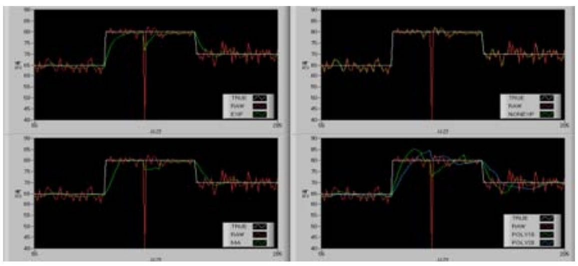

Fig. 2 Filtering result for exponential filter (upper-left), nonlinear exponential filter (upper-right), moving average filter (lower-left) and polynomial filter (lower-right)

The exponential filter can be analytically described by the following Equation (1):

$$y_k = \theta x_k + (1 - \theta) y_{k-1}, \qquad (1)$$

where y_k is filtered value at time t_k, x_k is measurement at time t_k and θ is filter parameter.

Depending on filter parameter θ, it is effective to reduce noise with spikes as shown in Fig. 2. However, significant noise attenuation is accompanied by relatively large delay in the filtered signal.

The nonlinear exponential filter, the general expression is in Equation (2):

$$y_k = y_{k-1} + \theta (x_k - y_{k-1}) = y_{k-1} + \theta \Delta x, \qquad (2)$$

This heavily filters the noise but does not filter out spikes at all while reducing the delay.

The moving average filter is easy to tune for steady-state or quasi-steady-state signals because different weights can be given depending on the sampling points. It is defined in Equation (3):

$$y_k = 1/N \sum x_i, \qquad (3)$$

where N is number of data points in filter.

To use the polynomial filter, the strength of filtering and the delay depend on the number of data points used and the order of polynomial. Equation for polynomial filter can be written in Equation (4):

$$y_k = b_m t_k^m + b_{m-1} t_k^{m-1} + \ldots + b_2 t_k^2 + b_1 t_k + b_0, \quad (4)$$

where t_k is current time, $b_0, \ldots, b_m$ is filter parameters.

For a given number of filter data points, the higher the polynomial order, the more closely the filtered response follows the measurement data. The high-frequency noise is not removed, however. The large delay occurs in the lower order. For a selected polynomial order, the larger the number of points used by the filter the more overshooting occurs.

Before-mentioned two kinds of filters, the Kalman filter and the bilateral filters belong to the different principles comparing the above four filters. The Kalman filter needs to model the system's states considering system's physics and control logics. The bilateral filters are similar to polynomial filter in terms of the management of both of time and space, but they have less overshooting and can preserve the edges for step changes.

It should be noticed that none of the individual filters behaves in a satisfactory manner for transient conditions. Therefore, it is reasonable to combine the features of different filters, and perform the arithmetic averaging of the filtered values from two types of filters. For instance, the combination of polynomial/moving average, polynomial /exponential, or exponential/nonlinear exponential can be recommended.

2.3 Demonstrations

Using the signals acquired from a PWR, the test bed and digital filters were evaluated. Fig. 3 shows the performance of polynomial/exponential filter, which is a proposed combination, for the mass of a volume control tank which is likely to be promptly changed due to injection and discharge. Using the user interfaces, we can try to have different options to get desired results by entering various filter algorithms directly in a flexible manner.

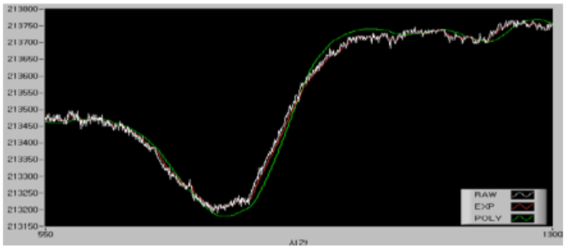

Fig. 3 Filtering results of a VCT mass

3. Conclusion

This study aims at developing the test bed to test and develop an advanced RCS leakage calculation program under the LabVIEW environment. The test bed can make use of various digital filter libraries in addition to its back-bone algorithm and provides user interface to connect on-line/off-line data acquisition. We are going to study more to make it practical forward for the applications to nuclear power plants.

ACKNOWLEDGEMENT

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