Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Study on On-line Monitoring Model for Sensor Integrity in Severe Accident

Hyeonmin Kim[a], Se Woo Cheon[a], Jae Chang Park[a], Sup Hur [a*]
[a] *Korea Atomic Energy Research Institute, 989-111 daedekodaero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: shur@kaeri.re.kr*

1. Introduction

The Fukushima accident brought a lot of changes to the nuclear field and also learned a lot lessons from the accident. One of the lessons is that in the event of severe accident, the accident is very dynamic and the emission of enormous heat and radiation that increases as accident progresses interrupts the operators to take appropriate response. However, there might be wholesome sensor in the early stage of severe accident or depending on the situation, and the use of the information of these sensor can help take appropriate measures against accidents. This research is intended to develop an on-line monitoring to determine the integrity of sensor using surrounding sensors with more sound integrity in the event of severe accidents. Many studies have been conducted on the material integrity and thermal-hydraulic phenomena according to the phenomena of severe accidents, yet the studies of the integrity of sensors in the accidents have seldom been conducted.

As a feasibility study, this study monitor the pressure sensor in the Reactor Coolant System (RCS) by calculating the pressure on the RCS using information of Emergency Core Cooling System (ECCS).

2. Background

This chapter addresses the method of on-line monitoring and fault detection which is the basis for determining the sensor integrity. In general, on-line monitoring combines the method of monitoring and fault detection, but in this chapter, it will be addressed separately for the sake of convenience.

2.1 On-line Monitoring

The monitoring module consist of two parts: the monitoring and fault detection. The monitoring describes a suite of activities for estimating system state and providing early warning of anomalous behavior. The monitoring module can be considered an error correction routine; the model gives its best estimate of the true value of the system variables. The monitoring methods can be roughly divided into physics-based models and data-based models [1].

If the underlying physics mechanisms of a system are well understood, then an analytical model based on fist principles can be designed to describe the expected nominal (or in some cases faulted) behavior based on measured system features or operating conditions. Physics-based models are attractive for engineering systems because they explicitly account for mechanical, material, and operational characteristics and they can be applied to a wide variety of operational and material conditions to understand behavior over a wider range of operation. However, these models can be costly and time-consuming to develop for large, complex systems, and developed models often have limited applicability. Additionally, simplifying assumptions are often necessary for phenomena that are not fully understood or to improve runtime performance.

Unlike physical models, data-based models are built on historical operation data with no explicitly defined understand of the underlying physical mechanisms of the system. These modeling methods can be classified according to two characteristic: parametric or nonparametric. Parametric models use the available data to determine the parameter values for a functional fit and then no use the historical data. Conversely, nonparametric models retain the historic exemplars in a memory matrix and include an algorithm for combining these exemplars to make a prediction for each new observation. The monitoring method is the Artificial Neural Network (ANN) and Auto-associative Kernel Regression (AAKR).

2.2. Fault Detection

The simplest method of fault detection is thresholding. Thresholding monitors a sensed value (or residual) and alarms when it exceeds some predefined, fixed threshold. This type of fault detection looks for gross changes in the sensor value. Care must be taken when setting the alarm threshold to balance between false alarms (due to noise naturally present in the system) and missed alarms (common when faults only induce small changes in a single variable). Advanced fault detection methods typically compare the nominal system state estimated by a physics-based model or data-based model to the system state measured by sensed variables to detect discrepancies between expected and actual behavior. The difference between expected and actual behavior, called the residual, characterizes system deviations from normal behavior and can be used to determine if the system is operating in an abnormal state. The fault detection method is Sequential Probability Ratio Test (SPRT) and Statistical Quality Chart (SQC) that is based on SPRT. The figure 1 shows concept of SQC.

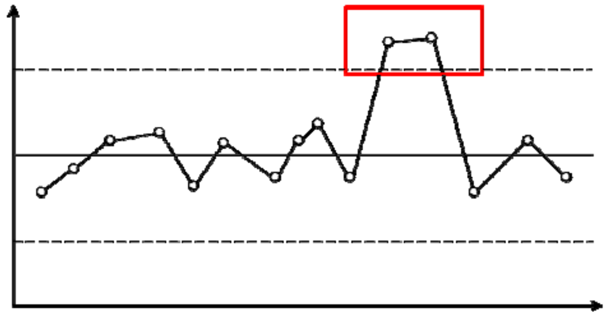

Fig 1. The concept of Statistical Quality Chart

3. Feasibility Study

As part of the project of "Development of an On-line integrity diagnosis technique for safety critical instrument" in the previous paper, the integrity of the sensors in a normal state was monitored using AAKR, which is one of data-based models, and the faults of sensors were detected using SPRT. However, in this paper, the authors will develop a model to monitor the integrity of the pressure sensor of RCS using the flow and pressure of ECCS in the severe accident as a feasibility study of the on-line monitoring, which is a physics-based model.

As shown in figure 2, a part of ECCS is outside the containment building, so it can be judged as having higher integrity than the sensors inside the containment building in accidents. The pressure on the RCS is calculated through the status of ECCS and then the sensor integrity on RCS is calculated using the method of fault detection.

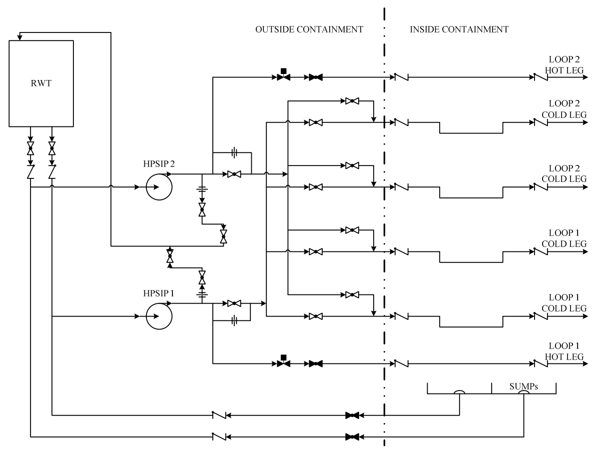

Fig 2. Schematic diagram of Emergency Core Cooling System (ECCS) – High Pressure injection operating mode

For the development of a physics-based model of ECCS, calculations will be made using the volume of Refueling Water Tank (RWT) and the pressure of the flow of ECCS. The main expressions are shown as below equation 1 and equation 2. The equation 1 is Bernoulli equation and equation 2 expresses pressure drop. ΔP in the equation 1 indicates pressure drop, which is the same as ΔP in the equation 2. The second term on the left in equation 1 indicates the pressure due to velocity and the third term indicates the pressure due to elevation.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \Delta P \qquad (1)$$

where, P is pressure
ρ is the density
v is the velocity
g is the gravity acceleration
h is the elevation

$$\Delta P = \left(f \frac{L}{D}\frac{1}{2} + K \right)\rho v^2 + \rho g h \qquad (2)$$

where, f is the friction factor
K is the form loss factor

The friction factor (f) in equation 2 is determined by the material and roughness of pipes, and form loss factor (K) is determined by the shape of pipe, which is determined by the state of ECCS.

4. Conclusions

This study has verified the feasibility of a physics-based model that monitors the integrity of sensors on a real-time basis using the surrounding sensors. In addition, this study calculated the pressure on the RCS using the model of ECCS as a feasibility study and verified the integrity of the pressure sensor in the RCS for monitoring model. Follow-up studies will verify this using the nuclear plant simulator data. This study aims to review the extension of other parts of the nuclear plant through verification thereby develop the technology for monitoring the faults of measuring instruments which is critical to the safety of nuclear plants and securing alternative information, which will facilitate the alleviation of accidents; and increase the safety of nuclear plant. Furthermore, it also aims to fundamentally resolve the problems with the reliability of the information in the severe accident since Fukushima accident, preventing the expansion of large scale accidents.

REFERENCES

[1] J.B. Coble, P. Ramuhalli, L.J. Bond, J.W. Hines, B.R. Upadhyaya, Prognostics and health management in nuclear power plants: a review of technologies and applications, PNNL-21515, U.S.DOE, pp. 4.13-16, 2012