ON-LINE AUTOMATIC SENSOR RESPONSE TIME ANALYSIS SYSTEM

M.H. Chen, C.D. Lee, C.C. Ma and D.J. Shieh
Institute of Nuclear Energy Research
P.O. Box 3-11, Lung-Tan,
Tao-Yuan, Taiwan, R.O.C.
886-3-471-1415

ABSTRACT

An on-line automatic sensor response time analysis system in Taipower's Maanshan PWR nuclear power plant is presented. The algorithm applied in the system is the noise analysis technique which is an indirect method of determining sensor response time. This technique includes the power spectral density analysis and the autoregressive analysis methods. The system can also be used for long-term surveillance of sensor performance trends and cross-comparison of redundant sensors for predictive maintenance purposes.

INTRODUCTION

The definition of the reactor trip system response time is the time interval from when the monitored parameter exceeds its trip setpoint at the sensor channel until loss of stationary gripper coil voltage. It is a regulatory requirement to periodically test the response times of reactor protection systems in nuclear power plants in order to assure that the reactor trip systems can be activated in safe time limits specified in Technical Specification. The test period is that at least one channel per trip unit should be tested within one cycle. The response time of a trip channel includes the responses of sensor, associated electronic circuits, and actuator. The tests can be performed section by section on the logic train, and then summed up to get the total response time of the channel. This paper discusses only the tests of the sensor part. The associated regulatory guide and standards are listed as follows:

- ISA S67.06, "Response Time Testing of Nuclear Safety Related Instrument Channels in Nuclear Power Plant".

For the time being, the sensor response time tests in Taipower's Maanshan nuclear power plant is according to the Surveillance Test Procedures 600-I-SB-1004. There are 52 safety-related sensors needed to be tested which include pressure, flow, level and temperature transmitters listed as follows:
- Hot Leg Temperature 1-3
- Cold Leg Temperature 1-3
- Steam Generator 1-3 Water Level 1-4
- Secondary Coolant Loop 1-3 Steam Pressure 1-4
- Primary Coolant Loop 1-3 Coolant Flow 1-3
- Pressurizer Pressure 1-3
- Pressurizer Level 1-3
- Turbine First Stage Pressure 1-2
- Containment Pressure 1-4
- Refueling Water Storage Tank (RWST) Level 1-4

The surveillance tests are performed when the reactor power is greater than 75% before outage. The equipment used for the tests is Westinghouse's Sensor Response and Automatic Rod Drop Test Set which adopts signals from 7300 electronic cabinets. The algorithm implemented in the test equipment is noise analysis method which should be carefully used for getting meaningful response time data. In this paper, the noise analysis method applied for sensor response time analysis is
reviewed by analyzing the signal data recorded in the Maanshan's Transient Recorder and Analyzer (TRA) system. Moreover, we also demonstrate that the quality of the TRA data is good enough for noise analysis applications. And then, an automatic sensor response time and performance monitoring system is designed based on these algorithms.

RESPONSE TIME TESTING METHODS

The response time testing methods for pressure transmitters include ramp or step input perturbation tests and power interrupt (PI) tests for force-balance type sensors. For temperature sensors, they are loop current step response (LCSR), self-heating and plunge tests. The noise analysis method is an in-situ method for determining response times of various types of sensors with advantages that it could be performed remotely from control room and doesn’t interfere with plant operation. The schematic diagram of process parameters measuring in nuclear power plant is shown in Figure 1. During normal operation, the process signals always have a small fluctuating part which is customarily called 'noise' in nuclear industry. The noise comes from the normal fluctuations in the process. The dynamic characteristics of the process and measurement instrumentation can be obtained by analyzing these signals. The noise analysis method applied for determining sensor response time includes two techniques which are power spectral density (PSD) analysis and autoregressive analysis methods.

According to Figure 1, the transfer function relationship of the measurement channel can be expressed as:

\[ O(f) = I(f)H(f) + n(f) \]

If \( n(f) \) is negligible, the above relationship expressed in power spectral density as:

\[ (PSD)_o = |H|^2(PSD)_i \]

If the process noise has a wide-range constant spectrum \((PSD)_i = \text{constant})\) relative to channel response, i.e. it is white noise with large enough frequency bandwidth, the dynamic characteristics of the output signal can be identical to that of the instrumentation (sensor). From above discussions, we can fit an appropriate model to the power spectral density of the output signal to get the relative transfer function of the sensor. And then, the response time can be calculated by performing step response calculation of the fitted transfer function. The response time (time constant) is defined to be the time the step response reaches 63% of its final steady state value.

Based on the same assumptions mentioned above, the output signal can be expressed with time-series autoregressive (AR) model as:

\[ O(t) = \sum_{i=1}^{n} a_i * O(t-i*\Delta t) + n(t) \]

where \( O(t) \) is the output signal in time domain, \( i \) is the order of the AR model, \( a_i \) is the fitted model parameters, and \( n(t) \) is random residual. Once the AR model of the output signal is established, the step response and time constant of the sensor can be calculated.

DATA ANALYSIS IN MAANSHAN PLANT

From the above discussions, the applications of noise analysis technique for sensor response time tests have qualitative meanings only when the
various assumptions are valid. In this section, safety-related sensors in Maanshan plant are analyzed to assess this method. The digitized data is recorded from TRA system which is part of the Emergency Response Facility (ERF). It is an on-line data acquisition system which acquires signal data of almost all the sensors in plant with sampling rate up to 100 Hz and is mainly used for post-trip or transient analysis. Both of the PSD analysis and AR methods are used to calculate sensor response times. Figure 2 shows the analysis plots of one of the flow sensors in Maanshan’s unit 1 reactor coolant system (RCS LOOP 1 FLOW 1). Table 1 lists the response time analysis results of this sensor for several data bases by both methods, and also, different analysis parameters such as fitted frequency ranges and added with band-pass filters in PSD curve fitting analysis. It shows that different results are obtained for different analysis parameters, and little variations of the results are obtained when these parameters are fixed. It will depend on the comparisons with direct test methods to decide which analysis condition will get the best results. As we can see from the analyzed results, the noise analysis technique can only be used to detect the sensor degradation with fixed input parameters for analysis, rather than for getting quantitative values of the response times.

Another example of analysis is the pressurizer pressure sensor (PZR PRESS 1) which is shown in Figure 3. The resonance peak of 0.65 Hz as shown in PSD plot is due to the effect of surge line which is a process dynamics and is conflict to the basic assumption of white noise so that the calculated response time is not valid. This example demonstrates that the noise analysis technique applied for sensor response time tests should be carefully validated for its physical meaning. It also indicates that although the resolution of this signal is very bad as shown in time-domain plot, useful informations can also be obtained if the number of analyzed data points is large enough due to that the noise analysis technique is basically a statistical method.

ANALYSIS SYSTEM FUNCTIONS

Based on the noise analysis algorithms described and tested as above, we have developed an user-friendly automatic sensor response time and performance analysis system based on the personal computer. The hardware structure of the system is shown in Figure 4 which adopts sensor signals from Maanshan’s TRA system based on PRIME 2755 computer. The software functions of the system include:
- Sensor response time analysis with PSD fitting and AR modelling methods.
- Cross-comparison of redundant sensors.
- Performance trends of sensors which can be PSD trends or sensor response trends.

Table 1. Response Time Calculation of RCS LOOP 1 FLOW 1 Sensor

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020 ~ 10 Hz</td>
<td>0.60 sec</td>
<td>0.43 sec</td>
<td>0.45 sec</td>
</tr>
<tr>
<td>0.125 ~ 8 Hz</td>
<td>0.50 sec</td>
<td>0.47 sec</td>
<td>0.44 sec</td>
</tr>
<tr>
<td>0.125 ~ 5 Hz</td>
<td>0.36 sec</td>
<td>0.35 sec</td>
<td>0.35 sec</td>
</tr>
<tr>
<td>0.125 ~ 5 Hz*</td>
<td>0.30 sec</td>
<td>0.28 sec</td>
<td>0.28 sec</td>
</tr>
<tr>
<td>AR Model</td>
<td>0.42 sec</td>
<td>0.34 sec</td>
<td>0.35 sec</td>
</tr>
</tbody>
</table>

* Added 0.4s/(1+0.4s) High-Pass Filter
Figure 2. Response Time Analysis Plots of RCS LOOP 1 FLOW 1 Sensor
Figure 3. Response Time Analysis Plots of PZR PRESS 1 Sensor

Figure 4. Hardware Structure of the Automatic Sensor Analysis System
CONCLUSIONS

1. An automatic sensor response time and performance analysis system is designed for sensor surveillance tests with the following advantages:
   - It reduces man-power and time consumption for sensor response time surveillance tests due to that most of the work is done by computer.
   - Long-term surveillance of sensor performance trends and cross-comparison of redundant sensors can be easily manipulated by the system for predictive maintenance of the sensors.

2. Because the process dynamics in the nuclear power plant are not always white noise and the analyzed results are greatly influenced by analysis parameters, the sensor response time analyzed by noise analysis technique only indicates the qualitative performance of the sensors but not the absolute response times. It can only be used to detect the degradation of the sensor responses.

3. The noise analysis methods for response time measurement get conservative values and should be validated by comparisons with other direct methods.

4. The frequency bandwidth of the process should be large enough compared to the dynamic response of the sensors for the application of noise analysis technique in sensor response measurements.

ACKNOWLEDGMENTS

The authors would like to thank the members in Taipower's Maanshan nuclear power plant for providing the sensor response tests data and for the help on recording TRA data, especially Mr. Golden Chen and Mr. Wun-Lung Young in Division of Nuclear Engineering and Mr. Sun-Bau Lin in Division of Instrumentation.

REFERENCES


Session 33
Plant Instrumentation and Control-II