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ON-LINE MEASUREMENTS OF RESPONSE TIME OF TEMPERATURE AND PRESSURE SENSORS IN PWRs

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ABSTRACT

A review of modern techniques for in-situ response time testing of resistance temperature detectors (RTDs), and pressure, level and flow transmitters is presented. These techniques have been developed and validated for use in pressurized and boiling water reactors. The significance of the modern techniques is that they permit testing of installed sensors at process operating conditions and thereby provide the actual in-service response times of the sensors.

I. INTRODUCTION

Response time testing is performed on RTDs and pressure transmitters in nuclear power plants to satisfy the plant technical specification requirements and comply with regulatory regulations. The tests are performed once every fuel cycle in most plants in the U.S. and some plants in Europe and other countries. In almost all of these plants, the response time measurements are performed using a method called the Loop Current Step Response (LCSR) test for RTDs and a method called the Noise Analysis technique for pressure, level, and flow transmitters.

This paper presents the details of the LCSR and Noise Analysis techniques. The advantage of these techniques is that they permit remote testing of sensors from outside the reactor containment and account for all installation and process condition effects on response time.

II. RESPONSE TIME TESTING OF RTDs

The response time of an RTD can be measured in a laboratory using a method called the plunge test. The plunge test provides a baseline response time value which is useful for comparing a group of RTDs or thermowells to ensure that they provide comparable and consistent response times. The plunge test is also useful for testing the response times of RTDs of different designs or manufacturers to determine which design or manufacturer provides a better response time.

The plunge test results have very little bearing on the response time of an RTD after it is installed in an operating process. Due to the effect of installation and process conditions, the response time of an installed RTD can only be identified by in-situ testing using the LCSR method.

The LCSR test is performed by connecting the RTD to one arm of a Wheatstone bridge and changing the bridge current from a few milliamperes to a level of about 40 to 80 milliamperes (mA). The step change in current produces Joule heating in the RTD element and causes its resistance to increase in proportion to the RTD's ability to dissipate the heat to the environment. The transient change in RTD resistance produces a transient voltage signal at the output of the Wheatstone bridge which is referred to as the LCSR transient or the LCSR data for the RTD (Figure 1). This transient is then analyzed to provide the response time of the RTD under the conditions tested. The analysis involves fitting the LCSR transient to a heat transfer model to transform the internal heating data to yield the transient response time of the RTD as if it was exposed to a sudden change in the surrounding temperature.(1)

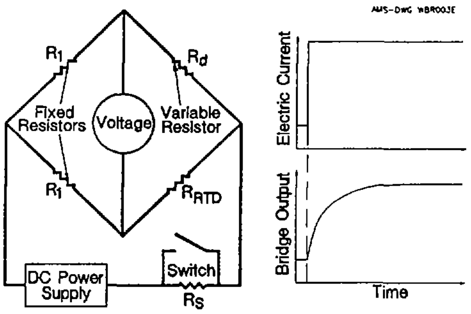

Figure 1. Illustration of Principle of LCSR Method for RTDs

The validity of the LCSR test depends on two assumptions about the physical location of the sensing element in the sensing tip of the sensor. The two assumptions are:

- The heat transfer between the sensor and its surrounding fluid must be one dimensional (radial).
- The sensing element of the sensor must be located at the center of the sensor assembly or there must be little heat capacity between the sensing element and the centerline of the sensor assembly.

These assumptions must be satisfied for the heat transfer to and from the sensing element to be unidirectional and for the LCSR transient to be transformable to the plunge test transient. The only reliable and practical method to ensure that these assumptions are adequately satisfied and that the LCSR test is valid for the RTD is to perform experimental measurements. The validation should involve a plunge test followed by an LCSR test performed under the same test conditions on each RTD design to be validated. The LCSR data is then analyzed, and the response time result is compared with that of the corresponding plunge test result to establish the validity and determine the accuracy of the LCSR method for the sensor design being validated.

Table 1 presents typical validation results for representative RTDs tested in the laboratory in room temperature water at a flow rate of 3 feet per second (~1 meter/second). The reasonable agreement between the plunge and the LCSR test results shown in this table indicates that the sensors shown are in-situ testable by the LCSR method. To date, the LCSR method has been validated for RTDs from a majority of manufacturers of nuclear-grade RTDs including Conax, Degussa, RdF, Rosemount, and Weed. Based on the results of these validations, the accuracy of the LCSR method has been established as ±10 percent.

The LCSR method can also be used for in-situ response time testing of installed thermocouples. The details of the LCSR method for thermocouples are presented in reference 2. Figure 2 shows the equipment setup for LCSR testing of a thermocouple. Unlike RTDs, the resistance of thermocouples is distributed along the thermocouple wire as opposed to being concentrated at the sensing junction. As such, the LCSR test of thermocouples requires a few amperes of heating current in contrast with RTDs that are tested with less than 100 mA. Furthermore, in LCSR testing of thermocouples, the sensor is first heated and its output is recorded after the heating is stopped (Figure 3).

Table 1

LCSR Validation Results

RTD Number	Response Time (sec) Plunge	Response Time (sec) LCSR	Percent Difference
1	7.1	7.2	1.4
2	6.3	6.6	4.8
3	4.9	4.9	0.0
4	5.2	5.3	1.9
5	2.8	2.6	-7.1
6	3.1	3.1	0.0
7	0.38	0.42	10.5
8	4.8	4.5	-6.3
9	4.6	4.2	-8.7
10	2.0	2.1	5.0
11	3.5	3.4	-2.9
12	2.7	2.9	7.4
13	11.7	12.3	5.1
14	2.0	2.1	5.0

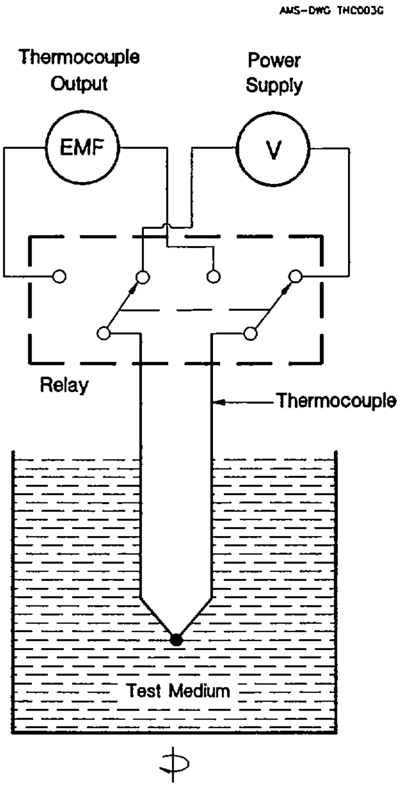

Figure 2. LCSR Test Setup for Thermocouples

III. RESPONSE TIME TESTING OF PRESSURE TRANSMITTERS

The conventional methods for response time testing of pressure transmitters usually involve a hydraulic pressure generator to produce a test signal in the form of a step or ramp. The ramp test is more commonly used than the step test because design basis accidents in nuclear power plants usually assume pressure transients which approximate a ramp.

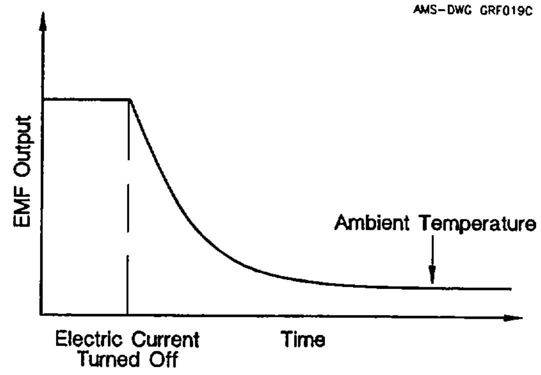

Figure 3. A Typical LCSR Transient for a Thermocouple

Figure 4 shows the schematic of a hydraulic pressure generator. The pressure test signal, as generated by this equipment, is applied to the transmitter under test and simultaneously to a high speed reference transmitter. The outputs of the two transmitters are recorded on a dual channel strip chart recorder or a similar device and used to identify the response time of the transmitter (Figure 5). Since the tests using the hydraulic pressure generator require physical access to each transmitter, and many transmitters are located in radiation environments of the plant, the noise analysis technique as described below was developed to allow us to perform the tests remotely.

The noise analysis technique is based on analyzing the natural fluctuations that exist at the output of pressure transmitters while the plant is operating. These pressure fluctuations (noise) are usually due to turbulence induced by the flow of water in the system, random heat transfer in the core, and other naturally occurring phenomena. The noise is superimposed on the DC output of the transmitter. It is extracted from the transmitter output by removing the DC component of the signal, and amplifying the AC component. The DC component is removed by passing the sensor output through a high-pass filter, or adding a negative bias to the output. This leaves the AC component which is

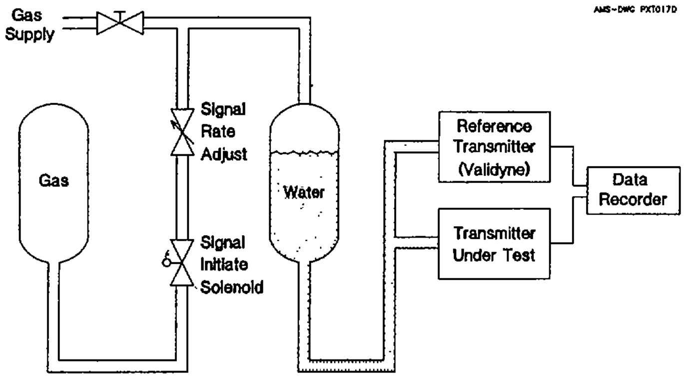

Figure 4. Hydraulic Ramp Generator

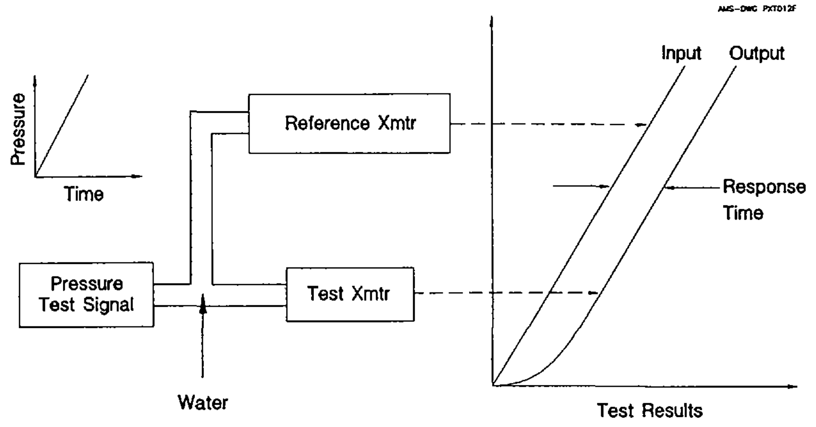

Figure 5. Illustration of Principle of Ramp Test

amplified and then passed through a low-pass filter for anti-aliasing and removal of high frequency electrical noise and interferences. The signal is then digitized by an analog to digital converter and subsequently analyzed (Figure 6).

The analysis of noise data is performed in the frequency domain and/or time domain, and is based on the assumption that the dynamic characteristics of the transmitter are linear. The frequency domain and time domain analyses are independent methods for response time determination of pressure transmitters, and it is usually helpful to analyze the data with both methods and average the results.

For frequency domain analysis, the Power Spectral Density (PSD) of the noise signal is obtained through a Fast Fourier Transform (FFT) algorithm. An appropriate mathematical function is then fit to the PSD from which the response time of the transmitter is calculated. The PSDs of nuclear plant pressure transmitters have various shapes depending on the plant, the transmitter installation and service, the process conditions, and other effects. Figure 7 shows three PSDs of the shapes usually seen in nuclear power plants.

In the time domain analysis, the raw noise data is processed with a univariate autoregressive (AR) modeling program to obtain the impulse response (i.e., response to a narrow pressure pulse) and then the step response of the transmitter from which the transmitter response time is calculated.

The validity of the noise analysis technique has been examined by laboratory testing of representative Barton, Foxboro, Rosemount, Tobar (Veritrak), Fischer & Porter, Schlumberger (Bailey), and Statham (Gould) pressure transmitters of the types used in nuclear power plants.(3) Based on the results of the laboratory validation tests, the noise analysis technique has been found to be successful in providing the response times of pressure transmitters to within better than ±0.10 seconds of the results that are obtained by the conventional ramp or step tests. Table 2 shows representative validation results for Barton and Rosemount transmitters. Similar results for several other transmitters are given in reference 3.

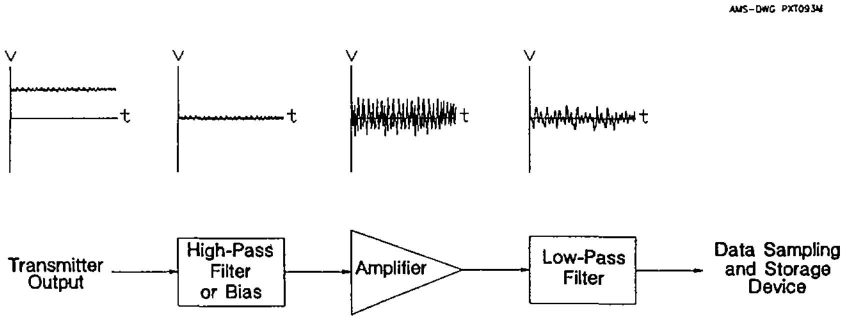

Figure 6. Noise Data Acquisition System for Pressure Transmitters

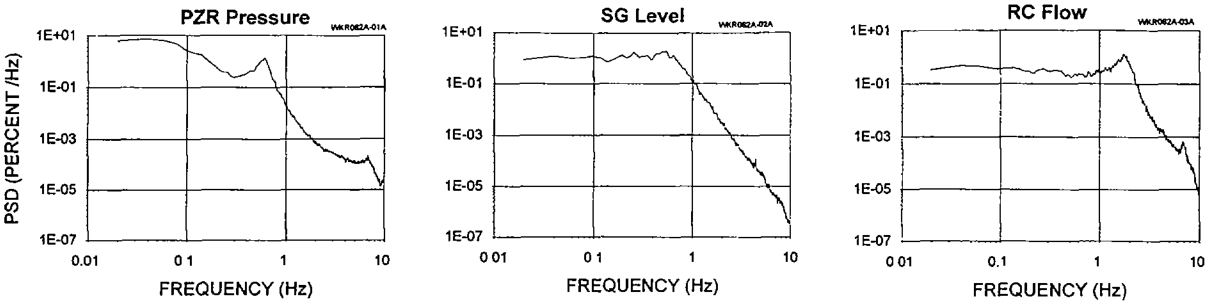

Figure 7. Typical PSDs of Nuclear Plant Transmitters

Table 2

Results of Laboratory Validation of Noise Analysis Technique for Pressure Transmitters

Transmitter Tag No.	Response Time (sec) Ramp	Noise	Difference
	Barton		
19	0.05	0.09	0.04
20	0.17	0.20	0.03
23	0.17	0.25	0.08
29	0.12	0.15	0.03
30	0.12	0.20	0.08
34	0.11	0.15	0.04
36	0.11	0.15	0.04
38	0.12	0.18	0.06
40	0.11	0.18	0.07
41	0.11	0.16	0.05
	Rosemount		
7	0.05	0.06	0.01
12	0.32	0.28	-0.04
21	0.07	0.08	0.01
21A	0.08	0.04	-0.04
61	0.07	0.05	-0.02
61A	0.11	0.04	-0.07
61B	0.10	0.07	-0.03
61C	0.11	0.08	-0.03
61D	0.09	0.08	-0.01
61E	0.09	0.08	-0.01
61F	0.10	0.09	-0.01
61G	0.09	0.09	0.00

A significant advantage of the noise analysis technique is that it can be used to test several transmitters at a time. To date, up to 15 transmitters have been tested at a time in nuclear power plants. This reduces the test time significantly and results in added cost savings. Figure 8 shows the equipment setup for in-plant acquisition of noise data for each transmitter.

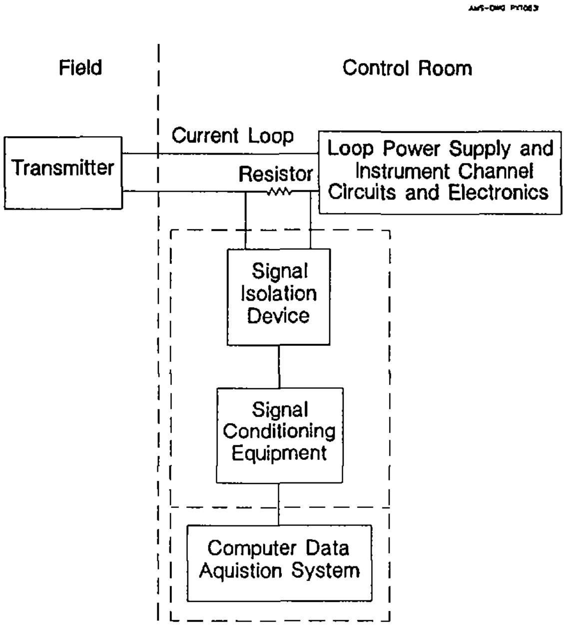

Figure 8. Test Setup for In-Plant Testing of Response Time of a Pressure Transmitter

IV. CONCLUSION

The response times of temperature and pressure sensors in nuclear power plants can be measured remotely from the control room area while the plant is operating. The test methods which can be used for these measurements were described in this paper. These methods have been validated and commercial equipment and services have been developed for routine testing in nuclear power plants.

V. REFERENCES

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2. Hashemian, H.M., "New Technology for Remote Testing of Response Time of Installed Thermocouples," United States Air Force, Arnold Engineering Development Center, Report Number AEDC-TR-91-26, Volume 1 - Background and General Details (January 1992).

3. Hashemian, H. M., et. al., "Long Term Performance and Aging Characteristics of Nuclear Plant Pressure Transmitters," NRC Report Number NUREG/CR-5851, U.S. Nuclear Regulatory Commission, Washington, D.C. (March 1993).