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AMS Fact Sheet:
RTD Response Time Testing Using the LCSR Technique

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1. INTRODUCTION

The Loop Current Step Response (LCSR) method, as approved by the U.S. Nuclear Regulatory Commission (NRC), is based on heating the sensing element of each Resistance Temperature Detector (RTD) by applying a small electrical current through the RTD's extension leads that are terminated in the plant protection system cabinets. The electrical current produces Joule heating in the sensing element of the RTD and results in an internal temperature transient that settles a few degrees above the temperature of the fluid outside the RTD. This transient is then analyzed to give the response time of the RTD under the actual installation and process conditions tested. The advantage of the LCSR test is that it provides in-situ testing capability at plant operating conditions and thereby yields the actual in-service response time of each RTD. The details of the LCSR method are described in this Fact Sheet.

AMS has been performing LCSR testing in nuclear power plants since the inception of the company in 1977. All testing is performed in accordance with our 10CFR50 Appendix B Quality Assurance program using verified and validated software and qualified personnel.

2. RTD RESPONSE TIME TESTING METHODS

Three methods are available for testing the dynamic characteristics of RTDs. These methods are referred to as the plunge, LCSR, and self-heating tests. The plunge method is used for laboratory testing of RTDs and the LCSR and self-heating tests are used for in-plant testing of RTDs. A description of each method is presented below.

2.1 Plunge Test

To identify the response time of an RTD in a laboratory environment, the plunge test is used. Typically, a plunge test involves suddenly moving the RTD from air into water at a different temperature than air. Figure 1 shows the principle of the plunge test. The test is usually performed in a rotating tank of water flowing at a rate of 1 meter/second as prescribed by the ASTM Standard E644. The response time of the RTD is calculated by determining the time that it takes for the sensor output to reach 63.2 percent of its final value following a step change in input that results from the plunge test.

It should be pointed out that although the above definition of response time is analytically meaningful only for a first-order system, it is conventionally used to determine the response time of most temperature sensors regardless of their dynamic order. For this reason, the term response time and time constant are often used interchangeably to describe the dynamic characteristics of RTDs even though the term "time constant" is relevant only for a first-order system.

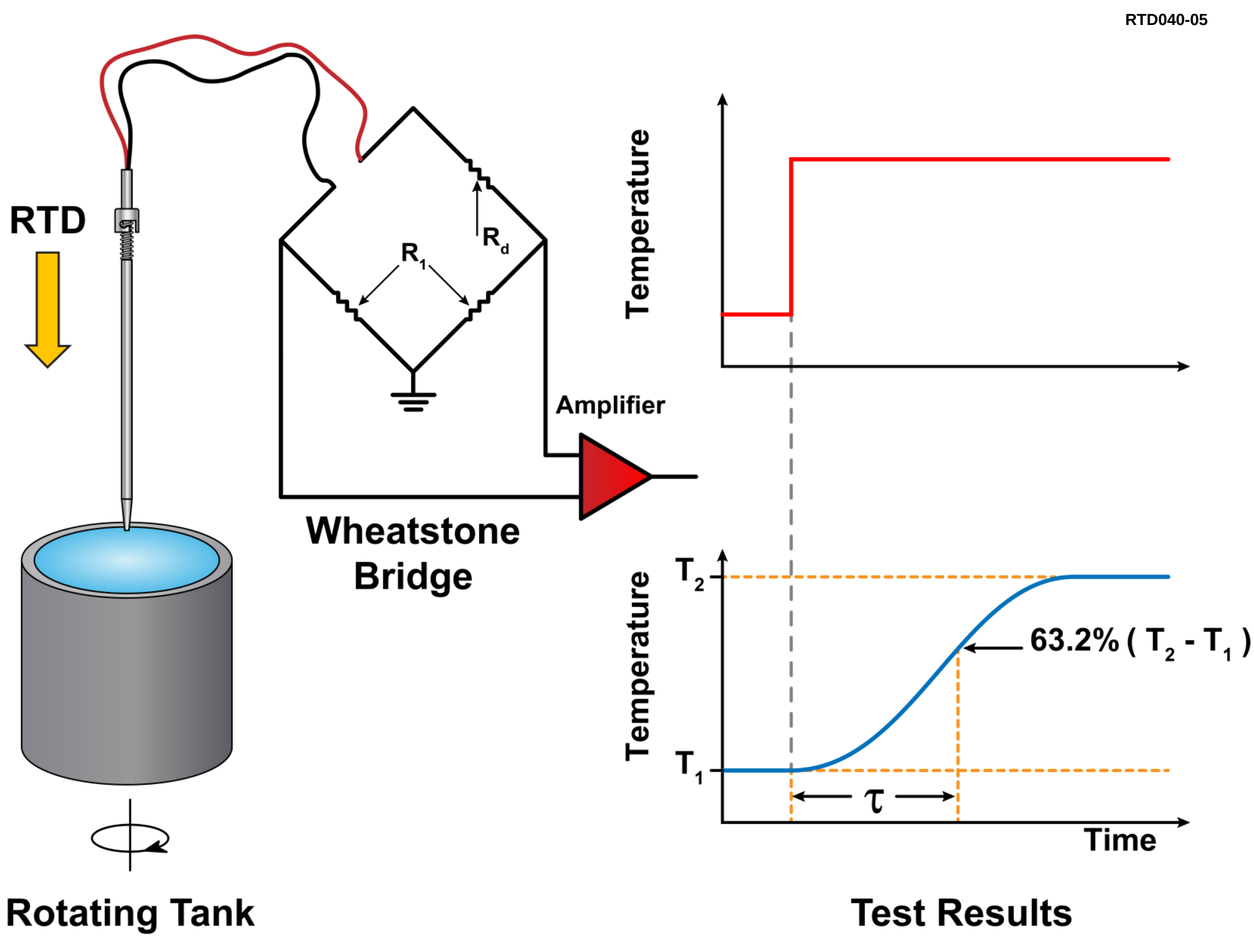

Figure 1. Principle of Plunge Test

2.2 Factors Affecting RTD Response Time

The response time of an RTD depends on the installation of the RTD in its thermowell (if one is used), the air gap in the thermowell, and the process conditions, such as fluid flow rate and fluid temperature. Therefore, the response time that is measured under laboratory conditions using a plunge test has little bearing on the response time of an RTD when it is installed in a plant. As such, the plunge test results are useful only for comparison of a group of RTDs and to ensure that an RTD has a reasonable response time before it is installed in a plant. After the sensor is installed in a plant, its true in-service response time can only be identified if it is tested in its normal configuration for service and while it is exposed to the process operating conditions. For this, the LCSR method was developed as described below.

2.3 LCSR Test

The LCSR test was developed and validated in the late-1970s and approved in the early-1980s by the NRC to measure the in-service response time of nuclear power plant RTDs. The test is performed remotely from the control room area while the plant is operating. If the RTD is used in a thermowell, the response time that is obtained from the LCSR test will include the dynamic response of the RTD and the thermowell combined, accounting for any air gap in the RTD thermowell interface. Furthermore, any process conditions (such as fluid flow rate and fluid temperature) that can affect the RTD response time are accounted for in the LCSR test.

To perform the LCSR test, a Wheatstone bridge is used along with a current switching network and signal conditioning equipment (Figure 2). The RTD is connected to one arm of the bridge and the bridge current is switched from about 1 or 2 mA to about 40 to 80 mA. This step change in current produces Joule heating in the RTD and results in a temperature transient in the RTD as illustrated in Figure 3. The temperature transient increases the RTD resistance gradually and produces a voltage transient at the output of the bridge. This transient data is then sampled by a computer and analyzed as described in Section 2.5 below to provide the response time of the RTD. AMS provides the test equipment, software, and personnel to perform these measurements in nuclear power plants.

2.4 Averaging of LCSR Data

The LCSR data usually contains fluctuations that are inherent in LCSR tests due to natural fluctuations in the plant temperature. Since the fluctuations can interfere with analysis of the LCSR data, they must be minimized. To do so, the LCSR test is repeated a number of times and the resulting LCSR transients are averaged to smooth out the fluctuations. The number of times that the LCSR test is repeated depends on the level of process fluctuations in the plant. Normally, 10 to 30 tests are needed.

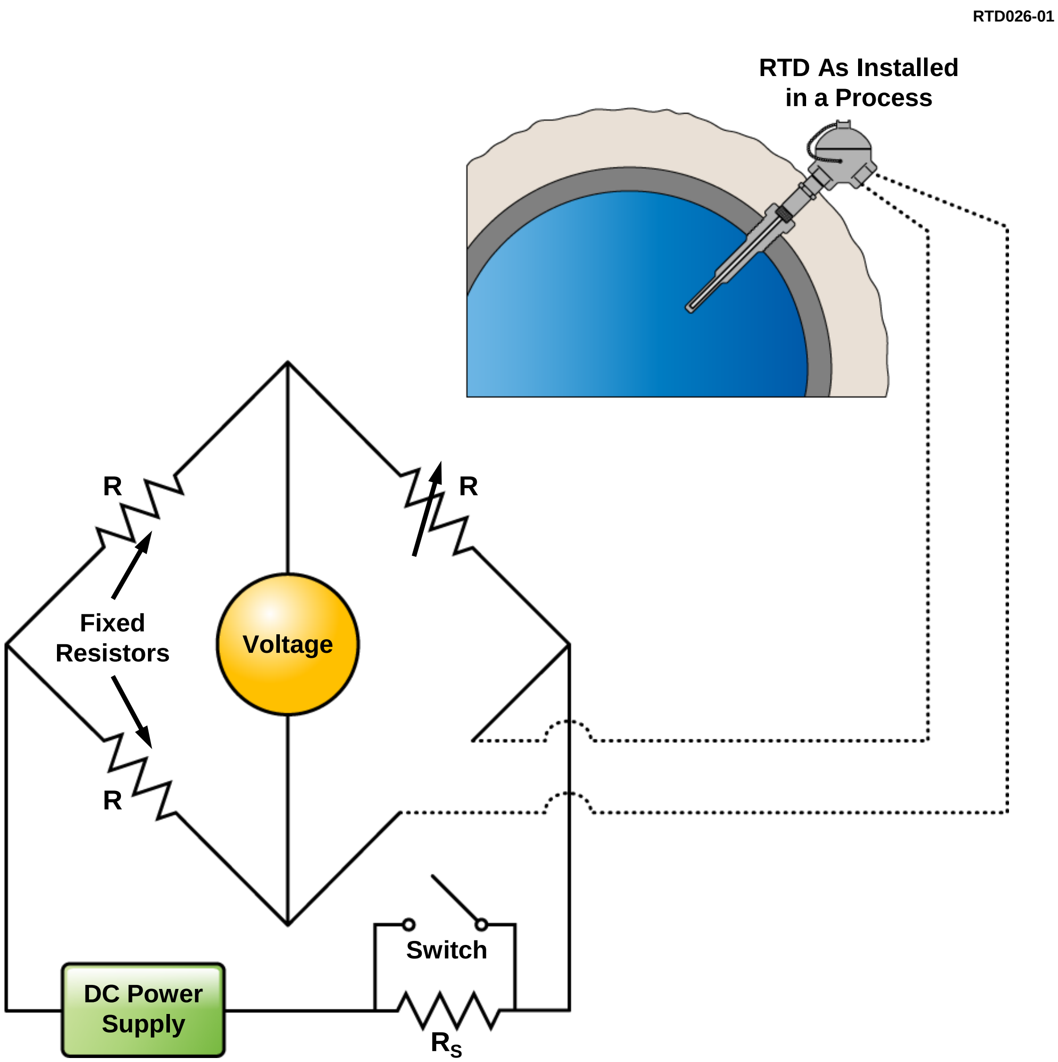

Figure 2. Wheatstone Bridge for LCSR Testing

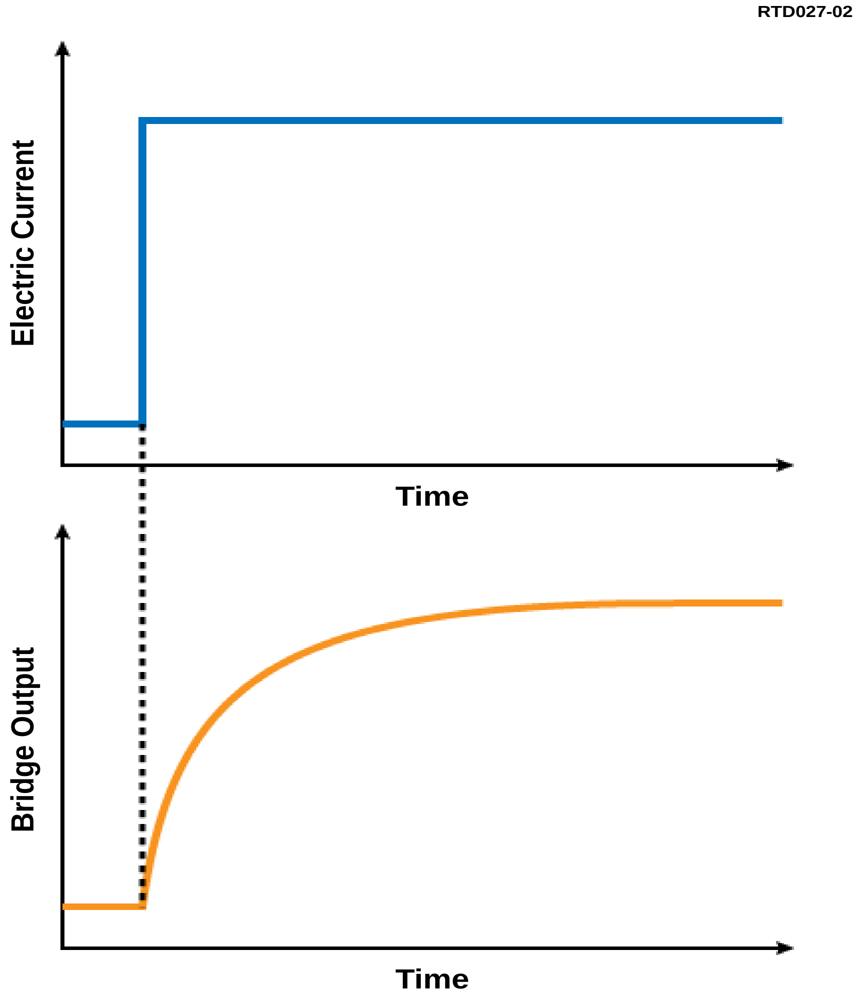

Figure 3. Illustration of LCSR Test Principle for RTDs

2.5 LCSR Analysis

The analysis of the LCSR data is based on a detailed heat transfer model of the RTD. During the development of the LCSR technique in the late-1970s, a detailed heat transfer model was developed for the LCSR analysis. To obtain the RTD response time, the LCSR data is fit to the model to identify the model parameters. The model parameters are then used to calculate the RTD response time.

2.6 Accuracy of LCSR Results

It has been shown by numerous laboratory experiments that the LCSR method provides the same response time as the plunge test (within ± 10 percent). This is provided that the geometry as well as the heat transfer characteristics of the sensing tip of the RTD meet the LCSR assumptions. As such, the validity of the LCSR assumptions must be established for each RTD design that is to be LCSR tested. This is accomplished by performing laboratory plunge and LCSR tests on several samples of each new RTD. The plunge and LCSR tests are performed under the same laboratory conditions and the goal is to prove that the LCSR test provides results that agree with the plunge test results to within ± 10 percent. In this case, the RTD is said to be "LCSR Testable".

2.7 LCSR Testing of Multiple RTDs

The LCSR test generally requires 20 to 80 seconds to perform. Including all other activities that are usually involved, the LCSR test of an RTD in a nuclear power plant typically requires 30 to 60 minutes of test time. To reduce the overall test time, multi-channel LCSR test equipment has been developed by AMS. With this equipment, five RTDs can be LCSR tested simultaneously. This helps reduce the LCSR test time to as little as 10 minutes per RTD.

2.8 Self-Heating Test

The self-heating test is sometimes performed as a supplement to the LCSR test. The test is often useful for cross checking the results of the LCSR tests and to monitor for gross degradation of RTD response time. Like the LCSR test, the self-heating test is based on heating the RTD internally with a small DC current applied to the RTD's extension leads. In this test, the steady state resistance of the RTD (R) is measured for different values of the applied electric current (I). The resulting data are then plotted in terms of the RTD resistance versus the electric power ($P=I^2R$) produced in the RTD element. The plot is referred to as the self-heating curve of the RTD. Figure 4 shows a typical self-heating curve of an RTD as tested in an operating PWR.

For platinum RTDs, the self-heating curve is normally a straight line whose slope is usually proportional to the RTD response time. Therefore, the self-heating test can be used to verify gross changes in RTD response time and to monitor for aging degradation of RTDs.

The correlation between the self-heating curve and the response time of an RTD depends on the design of the sensing element of the RTD and the installation and process conditions in which the RTD is tested. In some cases, the correlation is strong; and for some RTDs the correlation is weak. A weak correlation means that only large changes in self-heating indices are indicative of possible changes in RTD response time and vice versa.

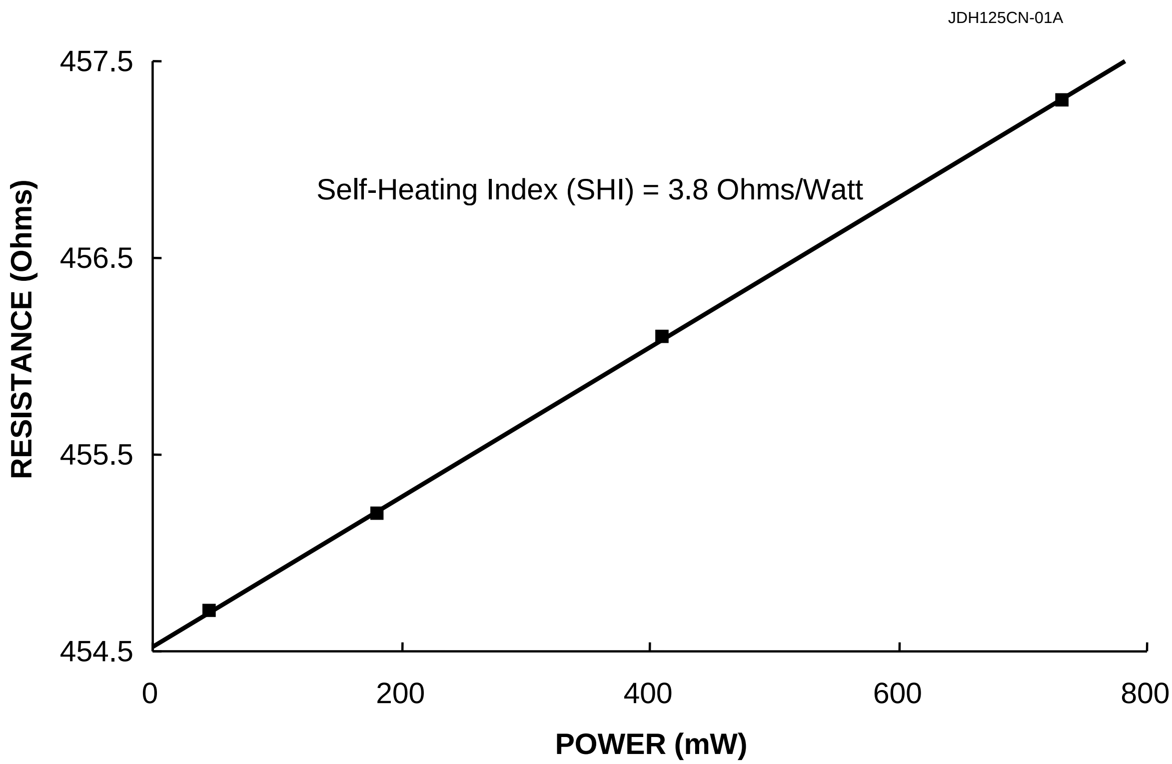

Figure 4. Typical Self-Heating Curve of an RTD