ISA-S67.06-1984

Approved August 29, 1986

Standard

Response Time Testing of Nuclear Safety-Related Instrument Channels in Nuclear Power Plants

ISA-S67.06 — Response Time Testing of Nuclear Safety-Related Instrument Channels in Nuclear Power Plants

ISBN 0-87664-847-2

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Preface

This preface is included for information purposes and is not a part of ISA-S67.06.

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The ISA Standards and Practices Department is aware of the growing need for attention to the metric system of units in general, and the International System of Units (SI) in particular, in the preparation of instrumentation standards. The Department is further aware of the benefits to U.S.A. users of ISA standards of incorporating suitable references to the SI (and the metric system) in their business and professional dealings with other countries. Toward this end, this Department will endeavor to introduce SI-acceptable metric units in all new and revised standards to the greatest extent possible. *The Metric Practice Guide*, which has been published by the Institute of Electrical and Electronics Engineers as ANSI/IEEE Std. 268-1982, and future revisions will be the reference guide for definitions, symbols, abbreviations, and conversion factors.

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The committee has determined that the terms "sensor" and "transducer" will be interchangeable throughout this standard. The term "sensor" is preferred due to its wider application. A sensor is considered to be the device which transforms the monitored variable into an intelligible signal.

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Contents

1 Scope

This standard delineates requirements and methods for determining the response time characteristics of nuclear safety-related instrument channels. The standard applies only to those instrument channels whose primary sensors measure pressure, temperature, or neutron flux.

2 Purpose

The purpose of this standard is to provide the nuclear power industry with requirements and acceptable methods for response time testing of nuclear safety-related instrument channels.

3 Definitions and terminology

Allowable response time: The limiting *response time* established in the safety analysis and documented in the plant's Technical Specifications.

Channel : An arrangement of components and modules as required to generate a single protective action signal when required by a generating station condition. A *channel* loses its identity where single-action signals are combined. (See Reference 1.)

Impulse line : Piping or tubing connecting the process to the *sensor*. (See Reference 2.)

Indirect test : A test that measures a quantity other than response time. The actual response time is determined using this quantity and previous measurements of this quantity which have a known relationship to the actual response times.

Instrument channel, response time : The time interval from the time when the monitored variable exceeds its trip setpoint until the time when a protective action is initiated.

Nuclear Safety-Related (NSR) : That which is essential to provide for:

1) emergency reactor shutdown
2) containment isolation
3) reactor core cooling
4) containment or reactor heat removal
5) prevention or mitigation of significant release of radioactive material into the environment, or that which is otherwise essential to provide reasonable assurance that a nuclear power plant can be operated without undue risk to the health and safety of the public

Response time characteristics : Those properties (e.g., transfer function, *time constant*, delay time, power spectral density) of the equipment from which its response time can be determined.

Response time, fluid transport : The response time associated with *fluid transport* from the location at which a property is to be measured to the sensor location. This delay may include contributions from both the transport time associated with fluid velocity and mixing times determined by mass flow rate and system configuration.

Sensor : That portion of a channel which responds to changes in a plant variable or condition, and which converts the measured process variable into an instrument signal. (See Reference 3.)

Setpoint : A predetermined level at which a bistable device changes state to indicate that the quantity under surveillance has reached the selected value. (See Reference 4.)

Step response time : Of a system or a component, the time required for an output to go through a specified percentage of the total excursion either before, or (in the absence of overshoot) as a result of a step change to the input.

> **NOTE:** This is usually stated for 90, 95, or 99 percent change.
>
> (See "time constant" for the use of a 63.2 percent value; see also Reference 4.)

Test interval : The elapsed time between the performance of tests.

Time constant : The value T in an exponential response term $A^{(-t/T)}$ or in one of the transform factors $1 + sT$, $1 + jwT$, $1/(1 + sT)$, $1/(1 + jwT)$ where:

s = complex variable

t = time, seconds

T = time constant

j = $\sqrt{-1}$

w = angular velocity, radians per second.

> **NOTE:** For the output of a first-order system forced by a step or an impulse, T is the time required to complete 63.2 percent of the total rise or decay; at any instant during the process, T is the quotient of the instantaneous rate of change divided into the change still to be completed. In higher order systems, there is a time constant for each of the first-order components of the process. In a Bode diagram, break points occur at $w = 1/T$. (See Reference 4.)

Unterminated ramp : A ramp that starts at the variable's initial value, becomes linear, and continues to a higher or lower value beyond the setpoint of interest, such that the instrument's or channel's desired output signal is obtained while the input ramp is still linear.

White noise: Random noise that has a constant energy per unit bandwidth at every frequency in the range of interest.

4 General criteria

Periodic testing shall be conducted to verify that response time characteristics of nuclear safety-related systems are within the limit assumed in the plant safety analysis and as defined in the plant's Technical Specifications. Tests to verify response time characteristics shall be performed in accordance with written procedures and the test results documented as specified in IEEE 338-1977, Section 6.6. (See Reference 5.)

5 Test boundaries

As presented herein, a response time verification test encompasses the instrument channel portion of the overall safety system. These tests' boundaries include impulse lines, thermowells, and all other components that affect the instrument channel response time.

6 General requirements for testing

6.1 The total instrument channel should be tested in a single test. When the total channel is not tested in a single test, separate tests on groups of components and/or on single components encompassing the total instrument channel shall be combined to verify total channel response. All active and passive components in the instrument channel shall be included to determine the overall channel response time. The response time obtained by adding the individual response times of each component or groups of components will be greater than or equal to the actual instrument channel response time.

6.2 -All testing shall be performed in situ. Equipment removal may be considered as an alternative only if it can be shown that such removal will not result in the elimination of testing of any portion of the channel that has an effect on the response time.

6.3 Calibration verification of instrument channels need not be performed in conjunction with response time testing if the instrument channel is within the required calibration interval. If at the time of response time testing the instrument channel exceeds its required calibration interval, or is found to be out of tolerance, the need to perform channel calibration prior to the response test shall be evaluated and documented. The evaluation shall include whether or not calibration adjustments could affect response times.

6.4 The test interval shall be established to detect an unacceptable response time. The test interval is determined by three factors: (1) the margin between the present test value of the response time and the allowable response time; (2) the time rate of change of response time; and (3) the reliability and qualification of as-built equipment.

6.5 Environmental or ambient effects on response time shall be covered in design qualification tests and need not be simulated during response time testing.

7 Test methods

Response time tests shall be conducted using direct or indirect response time measurements. Where indirect methods are used, a known quantitative relationship between the measured quantity and response time shall be established and periodically verified by direct measurement of response time.

8 Acceptance criteria for test methods

All test methods for response time measurement shall be validated by: (1) comparison with other direct methods in suitable laboratory or in situ tests; (2) through theoretical justification for the procedure; (3) through specification of assumptions and conditions that must be satisfied to ensure validity of the test; and (4) through verification that essential conditions for validity of the test exist during the in situ tests.

To be acceptable, indirect tests shall provide test results equal to or more conservative than direct response time tests.

9 Test equipment - general requirements

The calibration of test equipment used in verifying response time characteristics shall be traceable to the National Bureau of Standards.

The response time characteristics and accuracies of the dynamic test and recording equipment used in determining equipment response time characteristics shall be known and accounted for in determining test results. Test equipment shall have a known frequency response bandwidth that encompasses the allowable response time being verified. Test equipment accuracy shall be equal to or better than the required accuracy width and accuracy which are required to minimize the effect of test equipment characteristics on the test results.

10 Test results

Test results shall be compared to the allowable response time. If the results are found to exceed this limit, an investigation shall be performed to determine the cause. Repair or replacement shall be performed, as required. (See also Section 11.)

Where testing indicates a rate of change in response time characteristics such that the allowable response time may be exceeded prior to the next test, degradation is indicated and shall be investigated to determine the cause, and the appropriate action shall be taken.

Test results shall be documented and filed to ensure recoverability.

11 Maintenance

After any repair or replacement of material, parts, or components, the response time characteristics of that equipment shall be verified by test and test results documented, unless it is shown and documented that the repair or replacement cannot affect response time.

12 Test methods - specific requirements

Acceptable response time tests may be classified according to whether they are perturbation type or passive in nature. Perturbation tests require some direct means of stimulating the sensor or channel. Passive methods monitor inherent process fluctuations through the sensing system, and are referred to as "noise analysis." Both methods are discussed in the following subsections.

12.1 Instrument channels utilizing pressure sensors

This section includes all pressure-sensing applications, such as those for absolute pressure, differential pressure, level, flow, etc.

> **Caution:** Entrapped air in liquid pressure sensors can cause scatter in or unrepeatable test results. If acceptance criteria are exceeded, the cause of the scatter shall be investigated.

12.1.1 Substitute process perturbation

Where perturbation of the actual process variable is not a practical method of testing pressure channels, (e.g., reactor high pressure) channel perturbation shall be accomplished by utilizing a substitute pressure input test signal. The input test signal(s) shall simulate design basis event pressure transient(s) unless this is not practicable. If not practicable, one of the following alternatives shall be used:

1) Ramp input signal

This is a direct method of determining response time. To a first-order approximation, an unterminated ramp satisfies a majority of applications. (See Refs. 6, 7.)

In order to bound the response time of the channel in anticipation of potential degradation modes, apply to the transducer two ramps, as defined below. Do not deliberately pressure cycle the instrument prior to performing the tests.

Caution:Try to avoid any inadvertent pressure cycling prior to the test.

Apply the slow ramp first.

a) The first (slow) ramp shall be selected based on the slowest transients for which automatic protective action is required by design.

b) The second (fast) ramp shall be selected based on the fastest transient for which automatic protective action is required by design.

1) Other input signals

In some cases, alternate test input pressure perturbations which do not simulate the design basis event pressure transient are acceptable; for example, sinusoidal variations for frequency response or step inputs for time constant determinations. These specific examples are direct methods of determining response time. In these specific cases, the linearity property must be verified for the components tested. Test results shall then be converted to the equivalent response time for the components tested.

12.1.2 Noise analysis

This is an indirect method of determining response time.

1) Program description

The program described in this section is designed to detect a possible change in sensor response time of nuclear safety-related (NSR) sensors using the noise analysis technique. The normal fluctuations in the process variables are used as input to the sensor system. The response of the sensor can be analyzed in the time domain or the frequency domain. If the bandwidth over which the input noise spectrum appears is white and stationary and encompasses the sensor bandwidth, information on the sensor dynamics can be obtained. The sampling and statistical estimation schemes used shall be those necessary to provide valid results for the sensor bandwidth and to ensure statistically significant conclusions. If the input noise is not white, measurement of sensor output may be used to derive information about the change in the sensor's response time by detection of change in frequency content.

The program has two phases: the baseline measurement and the periodic surveillance phase. The baseline phase establishes the reference for the surveillance phase. Acquisition of data for the baseline phase of the program is normally limited to early operation of the plant or when new sensors are installed. The surveillance phase of the program is performed during normal operation of the plant, and evaluations are made by determining changes in response time in comparison with previous measurements.

A limitation of noise analysis for some pressure sensors is evidence showing that the sensors may respond differently for large and small perturbations. That is, some sensors exhibit a nonlinear dynamic behavior. If this is the case, monitoring of the process noise level will not be valid. It shall be the responsibility of the user to assure that dynamic linearity methods can be applied. Details of this program are outlined in Appendix A.

Baseline phase

The objective of this phase of the program is to establish the relationship between the actual measurement response time and the response at a baseline reference. This will be performed when the required process noise for the baseline measurement is present. In addition, acceptance criteria must be established for estimated changes in response time. These criteria must be consistent with the requirements in Section 8.

Surveillance phase

The objective of the surveillance phase of the program is to periodically determine whether changes in the response have occurred beyond acceptable limits. This may be done by either periodic noise measurements and analysis or by a suitable continuous surveillance monitoring system. This program is carried out over the lifetime of the equipment.

To determine if changes have occurred, it is necessary to reestablish the equipment at the baseline reference point, repeat the test, and perform the analysis which was carried out in the baseline phase.

The changes observed in the surveillance phase shall be compared to the previously established acceptance criteria from the baseline phase. Failure to meet acceptance criteria shall be investigated, including a direct measurement of response time.

Apparent changes in response time, indicated by these methods, do not mean that significant degradation necessarily occurred. Long-term, nonstationary process effects may be responsible. A change in sensor characteristics which did not produce significant response time degradation also might have occurred. At any time during the sensor's installed life, the baseline can be updated by repeating the previous steps in conjunction with actual measurement of response time.

2) Test methods

The test method for power spectral density, autoregressive analyses, and zero-crossing analyses consists of baseline and surveillance phases. These test phases are the same as those described in this section and in Appendix A.

12.1.3 Impulse lines

This is an indirect method for determining response time which has the validity of a direct method, and therefore the completion of Section 7 is not required.

1) Liquid

a) Verify that impulse line sizing is properly matched with the transmitter used and with the length of line required.

b) Verify that an appropriately conservative assumption on the allowance for unobstructed impulse line delays has been made in the value of response time (RT) used in the safety analysis for the overall channel response.

c) Verify during start-up testing and at the intervals required by the plant's Technical Specifications that the impulse line is not blocked to a specified extent. This may be accomplished by an examination of the line flow in the forward and reverse direction or in the direction required to initiate a safety action. If a line is suspected of having a partial blockage, a further investigation should be conducted to attempt to restore the line to its unobstructed condition.

2) Gas

Gas impulse lines with accessible process connections (for example, containment pressure) shall be response time tested using the methods outlined in Section 12.1.1. This test shall include the entire impulse line and primary sensor in one test. Gas impulse lines with inaccessible process connections shall be flow tested as described in Section 12.1.3. (See References 1, 6.)

3) Remainder of channel

The methods of Sections 12.1.1 and 12.5 can be used to test the remainder of the channel after it has been established that no significant degradation in impulse line flows has occurred.

12.2 Instrument channels utilizing temperature sensors

12.2.1 Resistance temperature detectors (RTDs)

1) Loop current step response

This is an indirect method for determining response time which has the validity of a direct method. In the loop current step response test, the sensor is heated internally by passing a current through the normal sensor leads. The resulting transient is analyzed to give the response time characteristics of the sensor. Analysis methods shall meet the requirements of Section 8. (See References 8, 10, 11.)

2) Noise analysis techniques

This is an indirect method for determining response time.

a) Program description

Noise analysis methods can be used to determine sensor degradation from a baseline reference. The general approach for using noise analysis in this manner is the same as that for pressure sensors. (See Section 12.1.2.) Unlike for pressure sensors, however, it is not necessary to verify that RTDs respond linearly for perturbations of different magnitudes.

b) Test methods

The test methods for power spectral density, autoregressive analysis, and zero-crossing analysis consists of baseline and surveillance phases. Those phases are the same as those described in Section 12.1.2 and in Appendix A.

3) Self heating

This is an indirect method for determining response time.

The self-heating method for RTDs can be used to determine sensor degradation from a baseline reference. The physical basis for the self-heating tests is that under steady-state process conditions the difference in RTD temperatures for different internal heat generation rates is inversely proportional to the overall heat transfer coefficient. (See References 8, 9.)

12.2.2 Thermocouples

1) Loop current step response

This is an indirect method for determining response time which has the validity of direct method. In the loop current step response test, the sensor is heated internally by passing a current through the normal sensor leads. The resulting transient is analyzed to give the response time characteristics of the sensor. Analysis methods shall meet the requirements of Section 8. (See References 8, 10, 11.)

2) Noise analysis techniques

This is an indirect method for determining response time.

a) Program description

Noise analysis methods can be used to determine sensor degradation from a baseline reference. The general approach for using noise analysis in this manner is the same as that for using pressure sensors. (See Section 12.1.2.) Unlike for pressure sensors, however, it is not necessary to verify that thermocouples respond linearly for perturbations of different magnitudes.

b) Test methods

The test method for power spectral density, autoregressive analysis, and zero-crossing analysis consists of baseline and surveillance phases. These test phases are the same as those described under Section 12.1.2 and in Appendix A.

12.2.3 Bypass lines

For temperature measurement systems that use bypass lines for sampling the process fluid, it is necessary to consider the effect of fluid transport in the bypass line on the channel response time. The contribution of fluid transport effects to the channel response time is a monotonically decreasing function of fluid mass flow rate.

The mass flow rate in the bypass line shall be verified to be greater than or equal to the flow rate value that corresponds to the allowed contribution to the channel response time from fluid transport effects. That is, any response time measurements for systems employing bypass lines must include, at least, a comparative flow measurement to determine whether flow in the bypass line is greater than or less than the value that corresponds to the allowed fluid transport response time. When a comparative flow measurement is used, the allowed fluid transport response time is added to the other components of the channel response time to assure a conservative total channel response time.

12.3 Instrument channels utilizing neutron sensors

There are several methods presently available in research and development for measuring these response times or determining degradation. These methods have not yet proven acceptable and therefore are not included herein.

12.4 Multiple input testing

For instrument channels with multiple inputs, the response time test shall be performed in accordance with IEEE 388-1977, Section 6.3.4, Paragraph 5. (See Reference 5.) The response time shall be determined for each process variable and shall be verified to be less than its allowable response time.

12.5 Remainder of channel testing

The remainder of the channel test shall be performed where the total channel (as described in Section 5) was not tested in a single test. This test will typically start at the sensor output and go to the channel output as required in Section 6.1.

Typically, the output of the sensor is transmitted to a signal conditioner. Signal conditioners are those components that receive the sensor output (RESISTANCE, MV, MA) and modify it. When the signal conditioning is integral to the bistable unit, it shall be tested as one assembly.

12.5.1 Step inputs

For bistables, the step input shall start at the initial value of the process variable (0 percent). The final value (100 percent point) of the step input shall be selected such that the trip point of the bistable occurs at greater than or equal to the 63 percent point. This way, the delay time at the trip point will be no less than the actual response time.

12.5.2 Ramp inputs

For ramp inputs, the response time shall be determined as follows:

1) A ramp test signal that simulates the sensor output for limiting design basis event transient shall be applied to the input of the signal converter.

2) The remainder of channel components shall be exercised through those set points identified in the technical specification which required initiation of a protective function.

3) The input and output signals shall be recorded. The response time shall be determined by measuring the time differential between the input and output signals at the channel trip point.

13 Design requirements

Special provisions shall be made in the design to facilitate channel response time testing in accordance with this standard.

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14.2 Bibliography

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Appendix A Noise analysis techniques

A.1 Power spectral density

Power spectral density analysis involves the determination of signal power per unit frequency as a function of frequency. For sensor response evaluation, the noise signal analyzed is the sensor output that results from normal process fluctuations. If the process fluctuations have a constant power spectrum (white noise over the nominal sensor bandwidth), then the power spectral density of the sensor output signal is proportional to the square of the frequency response gain of the sensor. Consequently, the sensor response characteristics can be evaluated by fitting a transfer function to the measured power spectral density if the white noise assumption is valid. This empirically determined transfer function then may be used to predict the response of the sensor to any input of interest.

If the white noise assumption is not valid, then the above procedure cannot be used. However, changes in the sensor response characteristic may alter a measured power spectral density.

A.2 Autoregressive analysis

Autoregressive analysis involves fitting a simple formula to the measured data. The formula has the form

$$\gamma_k = \sum_{i=1}^{i=N} a_i \gamma_{k-i}$$

where:

γ_k = sample k of the output

N = order of the fit

a_i = an autoregressive coefficient

The fit provides estimates of the a_i (usually obtained by least squares fitting techniques). Once the a_i are known, the autoregressive model may be used to evaluate sensor response characteristics. As with the power spectral density approach, the results are quantitative only if the process fluctuations have white noise characteristics.

A.3 Zero-crossing

The rate at which a sensor output crosses its average value in response to a specific fluctuating input decreases as the sensor time constant increases. Consequently, a device that monitors the crossing rate can be used to detect changes in sensor time constant and/or changes in input fluctuations. Masking of any effects due to changes in sensor time constant by exactly compensating changes in input fluctuations is implausible. Therefore, measuring the crossing rate will detect changes in the sensor time constant if the sensitivity of the crossing rate to changes in the time constant is large enough. For temperature sensors (where the response is governed by heat diffusion), the sensitivity is unity (an x percent increase in time constant causes an x percent decrease in crossing rate). The usual practice is to remove the average value of the signal and measure the rate of crossing of the zero value in the remaining signal. Consequently, the method is often called the zero-crossing technique.

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ISBN: 0-87664-847-2