Determination of Allowable Setpoint for Safety Instrument in Consideration of Uncertainty and Confidence Level

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Abstract: This paper is intended to determine a more practical allowable trip setpoint for safety I&C channels in research reactors considering not only measurement uncertainty but also the confidence level. For the safety channel, with an instrument loop, it is mandatory to have the allowable setpoint in accordance with the relevant standard in order to take swift safety actions such as a reactor shutdown. At this time, uncertainty for the instrument loop should be identified in a proper manner considering many conditions. In order to have a reliable setpoint, first we should figure out the detailed conditions of every sample test with the number of tests to find the coverage factor. Second, uncertainty of each component should be defined except for terms related to the overall error, and uncertainty of the total loop should be calculated with an adequate margin. In this paper, the two step process in determination of the setpoint for the safety channels is highlighted.

Keyword: *Uncertanty, Setpoint, Confidence level, Coverage factor*

1 Introduction

For a safety channel, with an instrument loop, it is mandatory to have the allowable setpoint in accordance with the relevant standard in order to take swift safety actions such as a reactor shutdown. At this time, uncertainty for the instrument loop should be identified in a proper manner considering the reference accuracy, inherent drift, measurement and test equipment, humidity and temperature condition, vibration and radiation effect and power supply variation. Although the calculation of uncertainty is correct, if the number of test trials and iterations are not sufficient, the outcome is not reliable. When we have investigated most of the data sheet related to safety instruments, the information on the total uncertainty was mostly available, whereas the confidence level of that uncertainty was not identified. According to GUM (Guide to the Expression of Uncertainty in Measurement), the uncertainty should be well defined such that it lies within a probability with a confidence level. If we do not have any data about the degrees of freedom or coverage factor, we cannot estimate the correct confidence level and consequently it leads to wrong uncertainty and setpoint. In order to attain the reliable setpoint, first, we should figure out the detailed conditions of every sample test with the number of tests to find the correct coverage factor. Second, the uncertainty of each component should be defined except for the terms related to overall error, and the uncertainty of total loop should be calculated with adequate margin based on ANSI/ISA-S67.04. In this paper, the two step process in determination of the setpoint for safety channels is highlighted.

2 Uncertainty and confidence level

2.1 Expended uncertainty and confidence level

According to ENB-6350/ISA-S67.04, the terms of uncertainty in the nuclear industry is defined as “the amount to which an instrument channel’s output is in doubt (or the allowance made therefore) due to possible errors, either random or systematic, that have not been corrected” For this reason, the uncertainty is generally identified within a probability and confidence level. The combined standard uncertainty is used to express the uncertainty of the measurement results, which is often required for a measure of uncertainty.

When it comes to uncertainty, first the error distribution is described whether an error or a range of errors is likely or unlikely to occur. It provides a mathematical description of how likely we are to experience certain values. With a basic understanding of error distributions and their statistics, we can estimate the uncertainties. The error terms should be defined to establish the component of uncertainty in the case of a direct measurement as follows: error source and distributions, repeatability (random error or measurement error), resolution error, operator bias and environmental factor errors. Except for an environmental factor error, the rest of the components can be directly obtained by tests and measurements. This error term is generally determined by the repetition of testing.

The interval of concern is also defined by how much the measurement results are spread within the measured values. The measure of uncertainty is ultimately obtained by sum of component error term with the confidence level multiplying the coverage factor, the value of which, in general, is chosen on the basis on the desired level of confidence to be associated with the interval. If 95/95 values were selected as an example, the 95/95 values bound the hardware performance with a 95% probability at a 95% confidence level. The probability value prescribes the portion of the population that is included within the tolerance interval.

The confidence level basically stipulates the repeatability of calculating a value that falls within the estimated values. Based on 100% confidence level, it means there is no doubt at all if you repeat the survey, the identical result would be taken. It says that if the values are to be recalculated, we have a 95% chance that the values would be confined by the 95/95 interval, which means 95% sure that 95% of all values is bounded within the estimated values. Typically, the coverage k lies within 2 to 3. Herein, the confidence coefficient is the confidence level stated as a proportion, rather than as a percentage. For example, if a confidence level is 99%, the confidence coefficient of 0.9 comes out. This confidence level and its coefficient are key parameters to ensure that the uncertainty level is established.

2.1 To determine the confidence level with coverage factor

The statistical methods stated in W.J. Beggs offer some guidelines to confirm the maximum values for as-found /as-left data regardless of the number of calibration intervals. Analysis of as-found/as-left data begins with setting up the scope of the analysis. Factors such as the process condition, range or environmental aspects, which may bring about more deviation, must be determined in advance. Once the scope is fixed, the next procedure is to acquire the as-found and as-left calibration data. All as-found and as-left data available are used to support the hypothesized distribution, which can have two ways of analyzing data: One is characterized by a normal distribution and the other is not subject to any specific distribution, and is rather likely to be random. The verification of normality is performed generally by using above 30 data points.

Once the as-found/as-left data are determined for individual devices, the data can be grouped by model and by groups with similar environmental conditions. When the groups have been established, the data can be analyzed. It is expected that most as-found and as-left data will be normally distributed. A method for analyzing this data for 95/95 interval values can be defined and referenced for tolerable uncertainty, which means the 95% of a population has the possibility of 95% to lie within the predefined limit of the setpoint.

The process of the uncertainty calculation can be divided into A type evaluation based on random error and B type with regard to SRSS (Square Root Sum of Squares), in which the extended uncertainty is finally obtained depending on the coverage factor k. The A type is acquired by the repeated measurement, whereas the B type is based on the distribution of the test results. The coverage factor k is determined by the required confidence level and the engineering judgment which takes into account the expertise on the test result, experience of test objective, and the environment. Accordingly, the determination of k is achieved by estimating the effective degree of freedom in extended uncertainty.

3 Uncertainty calculation and decision on setpoint

The setpoints of nuclear safety instruments are selected such that protective actions will initiate in a proper manner to mitigate the consequences of the reactor condition. For automatic setpoints related to severe safety, a rigorous setpoint methodology should be used. The choice of trip setpoint determined considering the margin of analytical limit under safety limit, requires determining the total loop uncertainty (TLU), which represents the expected performance of the instrument under any applicable process and environmental conditions. The margin of this TLU is chosen based on the methodology applied. Data used to calculate the TLU should be obtained from appropriate sources such as operating experience, equipment qualification tests, equipment specifications, engineering analysis, laboratory tests, and engineering drawings.

There are a number of recognized methods for combining instrumentation uncertainties. The method discussed herein is a combination of statistical and arithmetic methods that uses statistical square root sum of squares (SRSS) methods to combine random uncertainties, and then arithmetically combine the nonrandom terms with the result. If uncertainties that are random, normally distributed, and independent, the SRSS method is reasonable. When two independent uncertainties, (± a) and (± b), are combined by this method, the resulting uncertainty is (± c), where $c = SQRT(a^2 + b^2)$.

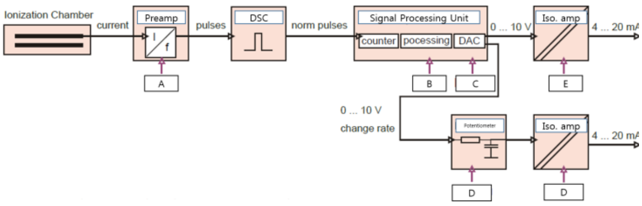

Fig.1 Instrument signal path

The uncertainty for a nuclear instrument herein is described as an exemplary, which is shown in Fig. 1, and the determination of the setpoint is considered as well. For analysis of the error term in each component of digital signal path, the preposition is needed in which the digital module is error-free because of no drift. Thus, the digital path from the preamplifier (A) becomes error-free. The dominating error term comes from A as shown in Table 1.

TABLE 1. Error Contributions

Module/Process	Label	Error Term
Preamplifier	A	2% + 1%/10K
Signal processing	B	0.3%
Analogue output	C	10mV/10K+10mV
Isolation amplifier	D	0.1%+0.1%/10K
potentiometer	E	0.1%

The temperature independent part is of limited relevance if this signal path is calibrated. The total error definitely depends on the signal level: assuming a signal level of 100%FS, equivalent to 10 V at the signal processing output (C), the total error at room temperature (ERT) is obtained by SRSS calculation from ERT of A and ERT of B. For example, if the calculation result is 1.5%FS with the case of relative error and full-scale error being identical, the total TLU comes to 1.5%FS because other error terms are negligible compared with this value. The combination of uncertainties is dependent on the distribution of the data, and an evaluation of the data is required. Most random uncertainties have to be assumed that the distribution of the data is a near normal distribution. However, practical data collected for a long time exhibit high kurtosis.

If the data do not meet the rigorous statistical definition of normality, some alternatives are required, one of which is to generate a histogram distribution and then the data are fitted to the desired level of probability. Thus, for a 95% coverage, only 5% of the data can be excluded in the normal curve. Other methods include curve fitting of alternate probability distribution functions and appropriate treatment of their characteristics. The coverage factor k enhances the reasonable justification by putting the expected probability into the uncertainty. The decision on the value of k is made by the degree of freedom with the confidence level as shown in Table 2. Thus, manufacturers made a decision on their own equipment's confidence level based on the degree of freedom, which corresponds to the number of experiments.

TABLE 2. Coverage Factor

Degree of Freedom	**Confidence Level p (%)**					
ν	68.27[(a)]	90	95	95.45[(a)]	99	99.73[(a)]
1	1.84	6.31	12.71	13.97	63.66	235.80
2	1.32	2.92	4.30	4.53	9.92	19.21
3	1.20	2.35	3.18	3.31	5.84	9.22
4	1.14	2.13	2.78	2.87	4.60	6.62
5	1.11	2.02	2.57	2.65	4.03	5.51
6	1.09	1.94	2.45	2.52	3.71	4.90
7	1.08	1.89	2.36	2.43	3.50	4.53
8	1.07	1.86	2.31	2.37	3.36	4.28
9	1.06	1.83	2.26	2.32	3.25	4.09
10	1.05	1.81	2.23	2.28	3.17	3.96
11	1.05	1.80	2.20	2.25	3.11	3.85
12	1.04	1.78	2.18	2.23	3.05	3.76
13	1.04	1.77	2.16	2.21	3.01	3.69
14	1.04	1.76	2.14	2.20	2.98	3.64
15	1.03	1.75	2.13	2.18	2.95	3.59
16	1.03	1.75	2.12	2.17	2.92	3.54
17	1.03	1.74	2.11	2.16	2.90	3.51
18	1.03	1.73	2.10	2.15	2.88	3.48
19	1.03	1.73	2.09	2.14	2.86	3.45
20	1.03	1.72	2.09	2.13	2.85	3.42
25	1.02	1.71	2.06	2.11	2.79	3.33
30	1.02	1.70	2.04	2.09	2.75	3.27
35	1.01	1.70	2.03	2.07	2.72	3.23
40	1.01	1.68	2.02	2.06	2.70	3.20
45	1.01	1.68	2.01	2.06	2.69	3.18
50	1.01	1.68	2.01	2.05	2.68	3.16
100	1.005	1.660	1.984	2.025	2.626	3.077

In order to determine the setpoint of the safety instrument, the margin is carefully chosen based on the methodology applied. The TLU has to take account of the effects of all applicable design-basis events (DBE) as well as the following: setting tolerance, temperature effect, error caused by DBE, measurement and test equipment (MTE) uncertainty, and instrument drift where applicable. The calculated margin should be considered for both operability and availability. If the margin is too rough and conservatively set, the trip setpoint reaches more closely to the normal operation, which leads to an unwanted frequent reactor shutdown. On the contrary, when the margin is taken too small, it may affect the safe operation of a reactor. For verification of the reasonable setpoint, instrumentation is periodically tested to ensure that the equipment performs as expected. The acceptance criteria for every performance test is based on a prediction of the expected performance of the tested instrumentation under the test conditions. These are typically limited to setting the tolerance, instrument uncertainties during normal operation, and MTE uncertainties. The performance test acceptance criteria may also be known as the as-found and as-left limits for the test being performed.

4 Conclusion

It was herein summarized how the practical allowable trip setpoint for safety instrumentation channel is determined considering not only measurement uncertainty but also confidence level. According to the implication for the reasonable decision of the setpoint, the uncertainty should be well defined such that it lies within a probability with a confidence level. For this, it is realized that the detailed conditions of every sample test with a number of tests to find the coverage factor and uncertainty of each component are required.

Acknowledgement

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References

[1] Introducing the Concept of Uncertainty of Measurement in Testing in Association with the Application of the Standard ISO/IEC 17025", ILAC-G17

[2] ANSI/ISA-67.04.01-2006 (R2011), Setpoints for Nuclear Safety-Related Instrumentation, AMERICAN NATIONAL STANDARD, 13 Oct.

[3] ISA–RP67.04.02–2010, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation, 10 December 2010

[4] BIPM JCGM 100:2008, Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM 1995 with minor corrections).