

CALIBRATION

A TECHNICIAN'S GUIDE

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ISA TECHNICIAN SERIES

**ISA—The Instrumentation, Systems,
and Automation Society**



CALIBRATION PRINCIPLES

After completing this chapter, you should be able to:

Define key terms relating to calibration and interpret the meaning of each.

Understand traceability requirements and how they are maintained.

Describe characteristics of a good control system technician.

Describe differences between bench calibration and field calibration. List the advantages and disadvantages of each.

Describe the differences between loop calibration and individual instrument calibration. List the advantages and disadvantages of each.

List the advantages and disadvantages of classifying instruments according to process importance—for example, critical, non-critical, reference only, OSHA, EPA, etc.

1.1 WHAT IS CALIBRATION?

There are as many definitions of calibration as there are methods. According to ISA's *The Automation, Systems, and Instrumentation Dictionary*, the word calibration is defined as "a test during which known values of measurand are applied to the transducer and corresponding output readings are recorded under specified conditions." The definition includes the capability to adjust the instrument to zero and to set the desired span. An interpretation of the definition would say that a calibration is a comparison of measuring equipment against a standard instrument of higher accuracy to detect, correlate, adjust, rectify and document the accuracy of the instrument being compared.

Typically, calibration of an instrument is checked at several points throughout the calibration range of the instrument. The *calibration range* is defined as "the region between the limits within which a quantity is measured, received or transmitted, expressed by stating the lower and

upper range values.” The limits are defined by the zero and span values. The *zero* value is the lower end of the range. *Span* is defined as the algebraic difference between the upper and lower range values. The calibration range may differ from the *instrument range*, which refers to the capability of the instrument. For example, an electronic pressure transmitter may have a nameplate instrument range of 0–750 pounds per square inch, gauge (psig) and output of 4-to-20 milliamps (mA). However, the engineer has determined the instrument will be calibrated for 0-to-300 psig = 4-to-20 mA. Therefore, the calibration range would be specified as 0-to-300 psig = 4-to-20 mA. In this example, the zero input value is 0 psig and zero output value is 4 mA. The input span is 300 psig and the output span is 16 mA.

Different terms may be used at your facility. Just be careful not to confuse the range the instrument is capable of with the range for which the instrument has been calibrated.

1.2 WHAT ARE THE CHARACTERISTICS OF A CALIBRATION?

Calibration Tolerance: Every calibration should be performed to a specified tolerance. The terms tolerance and accuracy are often used incorrectly. In ISA’s *The Automation, Systems, and Instrumentation Dictionary*, the definitions for each are as follows:

Accuracy: The ratio of the error to the full scale output or the ratio of the error to the output, expressed in percent span or percent reading, respectively.

Tolerance: Permissible deviation from a specified value; may be expressed in measurement units, percent of span, or percent of reading.

As you can see from the definitions, there are subtle differences between the terms. It is recommended that the tolerance, specified in measurement units, is used for the calibration requirements performed at your facility. By specifying an actual value, mistakes caused by calculating percentages of span or reading are eliminated. Also, tolerances should be specified in the units measured for the calibration.

For example, you are assigned to perform the calibration of the previously mentioned 0-to-300 psig pressure transmitter with a specified calibration tolerance of ± 2 psig. The output tolerance would be:

$$\begin{array}{r} 2 \text{ psig} \\ \div 300 \text{ psig} \\ \times 16 \text{ mA} \\ \hline 0.1067 \text{ mA} \end{array}$$

The calculated tolerance is rounded down to 0.10 mA, because rounding to 0.11 mA would exceed the calculated tolerance. It is recommended that both ± 2 psig and ± 0.10 mA tolerances appear on the calibration data sheet if the remote indications and output milliamp signal are recorded.

Note the manufacturer's specified accuracy for this instrument may be 0.25% full scale (FS). Calibration tolerances should not be assigned based on the manufacturer's specification only. Calibration tolerances should be determined from a combination of factors. These factors include:

- Requirements of the process
- Capability of available test equipment
- Consistency with similar instruments at your facility
- Manufacturer's specified tolerance

Example: The process requires $\pm 5^{\circ}\text{C}$; available test equipment is capable of $\pm 0.25^{\circ}\text{C}$; and manufacturer's stated accuracy is $\pm 0.25^{\circ}\text{C}$. The specified calibration tolerance must be between the process requirement and manufacturer's specified tolerance. Additionally the test equipment must be capable of the tolerance needed. A calibration tolerance of $\pm 1^{\circ}\text{C}$ might be assigned for consistency with similar instruments and to meet the recommended accuracy ratio of 4:1.

Accuracy Ratio: This term was used in the past to describe the relationship between the accuracy of the test standard and the accuracy of the instrument under test. The term is still used by those that do not understand uncertainty calculations (uncertainty is described below). A good rule of thumb is to ensure an accuracy ratio of 4:1 when performing calibrations. This means the instrument or standard used should be four times more accurate than the instrument being checked. Therefore, the test

equipment (such as a field standard) used to calibrate the process instrument should be four times more accurate than the process instrument, the laboratory standard used to calibrate the field standard should be four times more accurate than the field standard, and so on.

With today's technology, an accuracy ratio of 4:1 is becoming more difficult to achieve. Why is a 4:1 ratio recommended? Ensuring a 4:1 ratio will minimize the effect of the accuracy of the standard on the overall calibration accuracy. If a higher level standard is found to be out of tolerance by a factor of two, for example, the calibrations performed using that standard are less likely to be compromised.

Suppose we use our previous example of the test equipment with a tolerance of $\pm 0.25^{\circ}\text{C}$ and it is found to be 0.5°C out of tolerance during a scheduled calibration. Since we took into consideration an accuracy ratio of 4:1 and assigned a calibration tolerance of $\pm 1^{\circ}\text{C}$ to the process instrument, it is less likely that our calibration performed using that standard is compromised.

The out-of-tolerance standard still needs to be investigated by reverse traceability of all calibrations performed using the test standard. However, our assurance is high that the process instrument is within tolerance. If we had arbitrarily assigned a calibration tolerance of $\pm 0.25^{\circ}\text{C}$ to the process instrument, or used test equipment with a calibration tolerance of $\pm 1^{\circ}\text{C}$, we would not have the assurance that our process instrument is within calibration tolerance. This leads us to traceability.

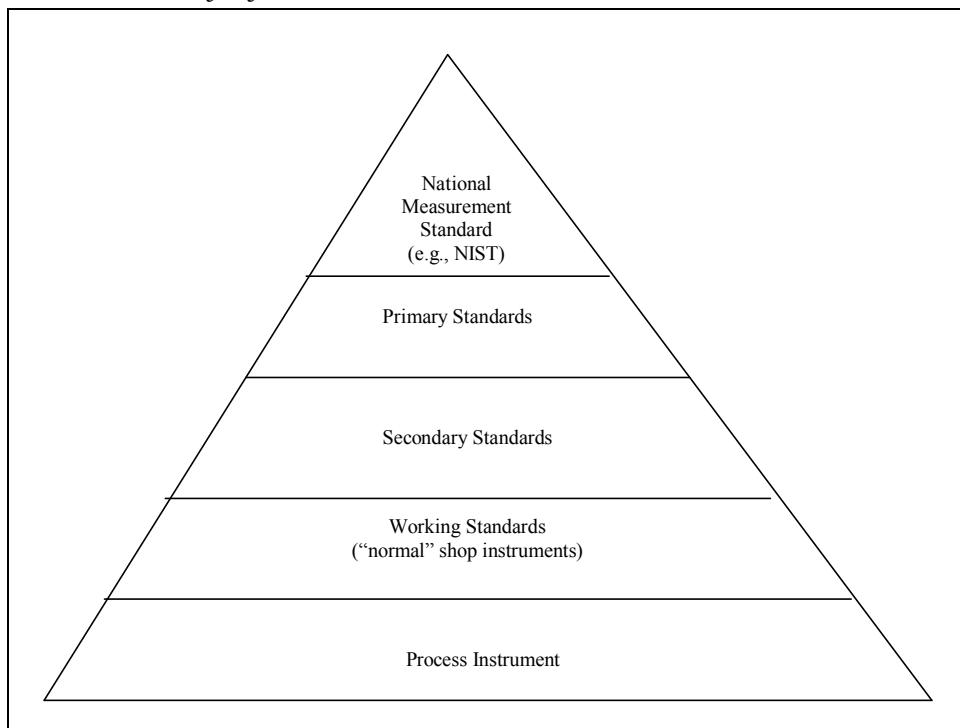
Traceability: All calibrations should be performed traceable to a nationally or internationally recognized standard. For example, in the United States, the National Institute of Standards and Technology (NIST), formerly National Bureau of Standards (NBS), maintains the nationally recognized standards. *Traceability* is defined by ANSI/NCSL Z540-1-1994 (which replaced MIL-STD-45662A) as "the property of a result of a measurement whereby it can be related to appropriate standards, generally national or international standards, through an unbroken chain of comparisons." Note this does not mean a calibration shop needs to have its standards calibrated with a primary standard. It means that the calibrations performed are traceable to NIST through all the standards used to calibrate the standards, no matter how many levels exist between the shop and NIST.

Traceability is accomplished by ensuring the test standards we use are routinely calibrated by "higher level" reference standards. Typically the standards we use from the shop are sent out periodically to a standards lab which has more accurate test equipment. The standards

from the calibration lab are periodically checked for calibration by “higher level” standards, and so on until eventually the standards are tested against Primary Standards maintained by NIST or another internationally recognized standard.

The calibration technician’s role in maintaining traceability is to ensure the test standard is within its calibration interval and the unique identifier is recorded on the applicable calibration data sheet when the instrument calibration is performed. Additionally, when test standards are calibrated, the calibration documentation must be reviewed for accuracy and to ensure it was performed using NIST traceable equipment.

FIGURE 1-1.
Traceability Pyramid



Uncertainty: Parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand. Uncertainty analysis is required for calibration labs conforming to ISO 17025 requirements. Uncertainty analysis is performed to evaluate and identify factors associated with the calibration equipment and process instrument that affect the calibration accuracy. Calibration technicians should be aware of basic uncertainty analysis factors, such as environmental effects and how to combine

multiple calibration equipment accuracies to arrive at a single calibration equipment accuracy. Combining multiple calibration equipment or process instrument accuracies is done by calculating the square root of the sum of the squares, illustrated below:

Calibration equipment combined accuracy

$$\sqrt{(\text{calibrator1 error})^2 + (\text{calibrator2 error})^2 + (\text{etc. error})^2}$$

Process instrument combined accuracy

$$\sqrt{(\text{sensor error})^2 + (\text{transmitter error})^2 + (\text{indicator error})^2 + (\text{etc. error})^2}$$

1.3 WHY IS CALIBRATION REQUIRED?

It makes sense that calibration is required for a new instrument. We want to make sure the instrument is providing accurate indication or output signal when it is installed. But why can't we just leave it alone as long as the instrument is operating properly and continues to provide the indication we expect?

Instrument error can occur due to a variety of factors: drift, environment, electrical supply, addition of components to the output loop, process changes, etc. Since a calibration is performed by comparing or applying a known signal to the instrument under test, errors are detected by performing a calibration. An error is the algebraic difference between the indication and the actual value of the measured variable. Typical errors that occur include:

FIGURE 1-2.
Span Error

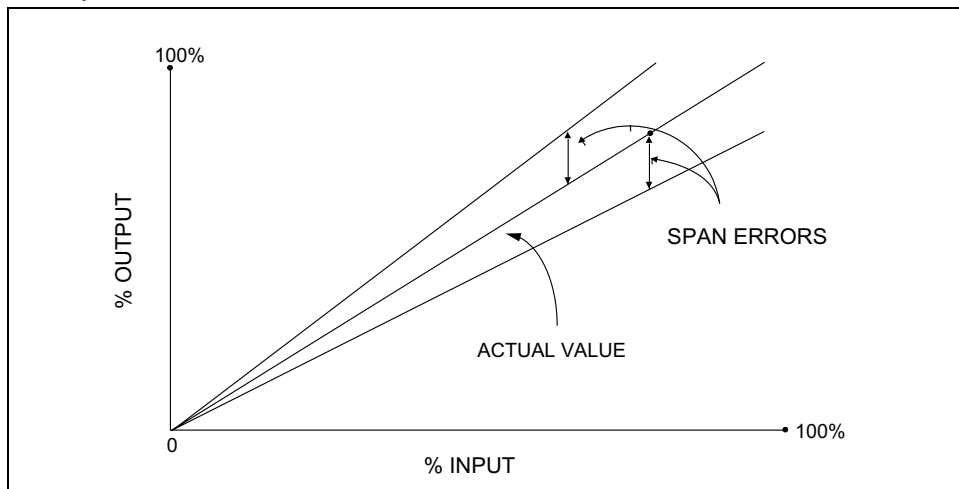


FIGURE 1-3.
Zero Error

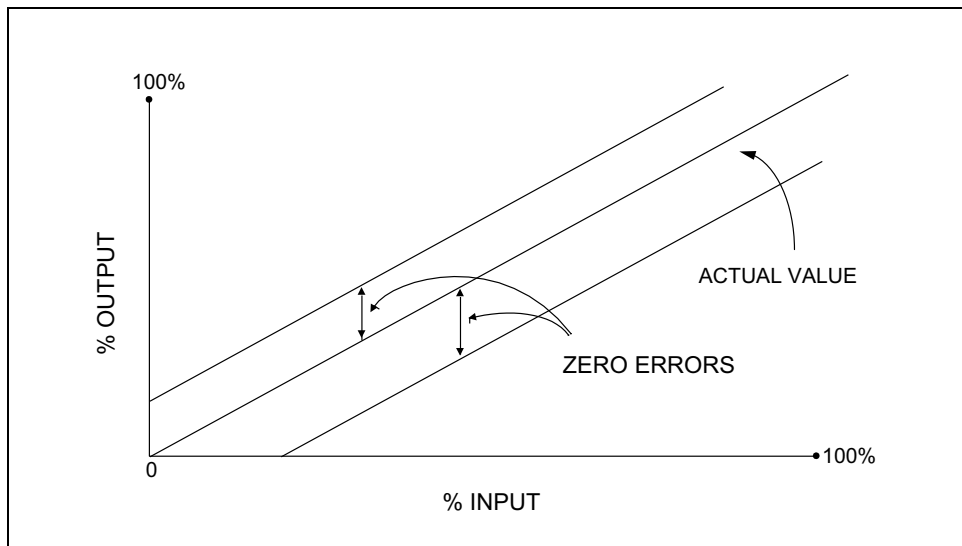


FIGURE 1-4.
Combined Zero and Span Error

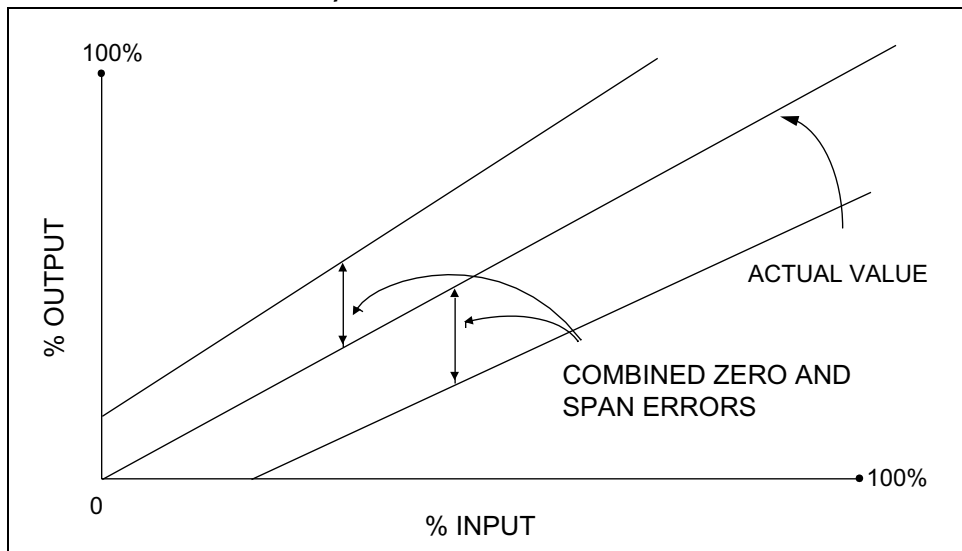
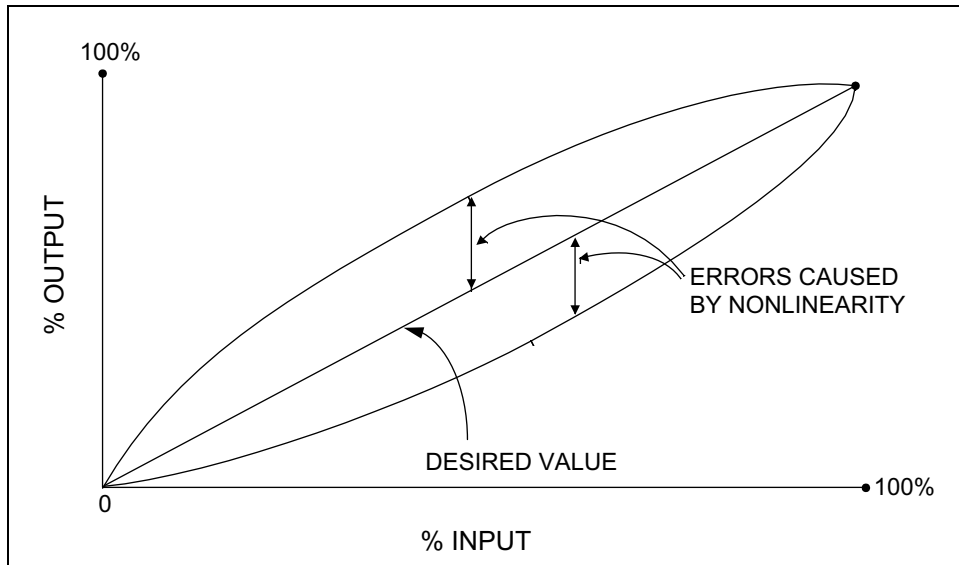


FIGURE 1-5.
Linearization Error



Zero and span errors are corrected by performing a calibration. Most instruments are provided with a means of adjusting the zero and span of the instrument, along with instructions for performing this adjustment. The zero adjustment is used to produce a parallel shift of the input-output curve. The span adjustment is used to change the slope of the input-output curve. Linearization error may be corrected if the instrument has a linearization adjustment. If the magnitude of the nonlinear error is unacceptable and it cannot be adjusted, the instrument must be replaced.

To detect and correct instrument error, periodic calibrations are performed. Even if a periodic calibration reveals the instrument is perfect and no adjustment is required, we would not have known that unless we performed the calibration. And even if adjustments are not required for several consecutive calibrations, we will still perform the calibration check at the next scheduled due date. Periodic calibrations to specified tolerances using approved procedures are an important element of any quality system.

1.4 WHO PERFORMS CALIBRATIONS? – THE CONTROL SYSTEM TECHNICIAN

A control system technician (CST) is a skilled craftsperson who knows pneumatic, mechanical, and electrical instrumentation. He or she understands process control loops and process control systems, including

those that are computer-based. Typically, he or she has received training in such specialized subjects as theory of control, analog and/or digital electronics, microprocessors and/or computers, and the operation and maintenance of particular lines of field instrumentation.

A CST performs calibration, documentation, loop checks, troubleshooting, and repair or replacement of instrumentation. These tasks relate to systems that measure and control level, temperature, pressure, flow, force, power, position, motion, physical properties, chemical composition and other process variables.

1.5 CHARACTERISTICS OF A CONTROL SYSTEM TECHNICIAN

Honesty and Integrity: A CST must possess honesty and integrity above all else. Most technicians work independently much of the time. Calibrations must be performed in accordance with procedures and must be properly documented. Additionally, the calibration department may be understaffed and production schedules may demand unrealistic completion requirements. These factors can have a real impact on proper performance and documentation of calibrations. Remember: Nobody can take away your integrity; only you can give it away.

Attention to Detail: Calibrations should be performed in accordance with detailed instructions. Each different make/model instrument is adjusted differently. Each instrument is installed in a different physical and loop configuration. Because of these and many other differences, attention to detail is very important. The minute a technician is not paying attention to detail, safety and proper performance are jeopardized.

Excellent Documentation Practices: In many facilities, the impression of quality is determined by the content and appearance of documentation. Many technicians complain the paperwork is 90% of the work. In today's world of ISO9000, cGMPs, A2LA, and other quality standards, documentation is essential. If it isn't documented, it wasn't done. Calibration Data Sheets must be neat, complete, signed and, if required, reviewed in a timely manner. When changes occur, all related documentation, such as drawings, manuals, specifications and databases must also be updated.

Understanding of Processes: One thing that sets technicians apart is an understanding of the process, particularly how the instruments monitor and control the process. There is a difference between calibrating an individual component and calibrating an instrument as part of the bigger process control loop. For example, knowing when a controller can be placed in manual without affecting the process and what to do while that controller is in manual, requires an understanding of the process. Additionally, when an operator says there is a problem with his indication, a technician who knows the instrument loop and process will be more capable of identifying the cause of the problem.

Some basic concepts on how calibrations should be performed need to be discussed before we go on. Some of these may be new concepts not used in your facility, but you should be familiar with them. Some of these practices are industry dependent. Although calibrations are generally performed the same, some different practices have developed. These practices are:

- Loop Calibration vs. Individual Instrument Calibration
- Bench Calibration vs. Field Calibration
- Classification of Instruments as Critical, Non-Critical, For Reference Only, etc.

1.6 LOOP CALIBRATION VS. INDIVIDUAL INSTRUMENT CALIBRATION

An *individual instrument calibration* is a calibration performed only on one instrument. The input and output are disconnected. A known source is applied to the input, and the output is measured at various data points throughout the calibration range. The instrument is adjusted, if necessary, and calibration is checked.

DISADVANTAGES OF INDIVIDUAL CALIBRATION	ADVANTAGES OF INDIVIDUAL CALIBRATION
1. Entire loop is not verified within tolerance 2. Mistakes on re-connect 3. Less efficient use of time to do one calibration for each loop instrument as opposed to one calibration for the loop	1. Correct instrument will be adjusted 2. More compatible with multifunction calibrators

A *loop calibration* is performed from the sensor to all loop indications with all the loop components connected. For example, a temperature sensor connected to a temperature transmitter would be inserted in a temperature bath/block. (Note: Either the bath/block would be calibrated or a temperature standard would be used in the bath/block for traceability.) The temperature of the bath/block would be adjusted to each data point required to perform the calibration. All local and remote indications would be recorded. It is also recommended to record the transmitter output. If all indications and transmitter output are within tolerance, the loop is within tolerance. If any loop component is not within tolerance, then a calibration is performed on that instrument. Do not adjust a transmitter to correct a remote indication.

ADVANTAGES OF LOOP CALIBRATION	DISADVANTAGES OF LOOP CALIBRATION
1. Entire loop, including sensor, is verified within tolerance 2. Mistakes on re-connect minimized 3. More efficient use of time to do one calibration for loop as opposed to one calibration for each loop instrument	1. Wrong instrument may be adjusted to bring the loop within calibration 2. Not as compatible with multifunction calibrators used for “paperless” data collection

1.7 BENCH CALIBRATION VS. FIELD CALIBRATION

A *bench calibration* is performed in the shop on the bench with power supplied from an external source, if required. Bench calibrations may be performed upon receipt of new instruments prior to installation. This provides assurance the instrument is received undamaged. This also allows configuration and calibration in a more favorable environment. Some companies perform the periodic calibrations on the bench. In this case the process instrument is removed from service, disconnected and taken to the shop for calibration. In some instances, a spare is installed in its place so the process downtime is minimized. For example, critical flow sensors might be sent out to a certified flow calibration facility. To prevent shutting the process down for several weeks, a replacement flow sensor would be installed.

Field calibrations are performed “in-situ,” or in place, as installed. The instrument being calibrated is not removed from the installed location. Field calibrations may be performed after installation to ensure proper

connections and configuration. Periodic calibrations are more likely to be performed in the field. Field calibrations are performed in the environment in which the instrument operates. If the instrument is installed in a harsh environment it is calibrated for that environment. If the instrument is removed for a bench calibration and then returned, some error may be introduced due to the ambient conditions and orientation.

ADVANTAGES OF BENCH CALIBRATION	ADVANTAGES OF FIELD CALIBRATION
1. Removed, cleaned, inspected 2. Better work environment 3. Fixed calibration setup and utilities (electrical, air, vacuum) available	1. May save time 2. May identify and allow troubleshooting of installation problems 3. Performed in actual ambient environment

1.8 CLASSIFICATION OF INSTRUMENTS

In some industries or even within individual companies it may be advantageous to classify your instruments in a way that indicates the instruments' "importance." There are two schools of thought here. Some say that no instrument is more important than any other instrument. However, in some processes, the undetected error in an instrument may result in product rejections or even product recalls. Additionally, some instruments have calibration requirements specified by outside agencies. For these reasons, it is recommended that each instrument is assigned a classification. ISA-TR91.00.02-2003, *Criticality Classification Guideline for Instrumentation*, is an excellent resource to assist with establishing classification of instrumentation. One example used for classifying instruments is outlined below.

Critical: An instrument which, if not conforming to specification, could potentially compromise product or process quality.

Non-critical: An instrument whose function is not critical to product or process quality, but whose function is more of an operational significance. Example: An instrument that is not classified as critical, but the reading obtained from the instrument is recorded in operating logs.

Reference Only: An instrument whose function is not critical to product quality, not significant to equipment operation, and not used for making

quality decisions. Routine calibration may be less frequent and verification of proper operation will be performed if suspect of error.

OSHA: Calibration of the instrument is mandated by the Occupational Safety and Health Administration.

EPA: Calibration of the instrument is mandated by the EPA. Example: Calibration of the flow totalizer for the wastewater treatment system may be required by EPA.

The above classifications may be helpful in assigning calibration frequencies. For example, you might assign a calibration frequency of six months to a “Critical” pressure transmitter. The same pressure transmitter assigned as “Non-critical” might be calibrated every 12 months.

Another advantage to assigning classifications is to investigate out-of-tolerance calibrations more efficiently. In many industries, out-of-tolerance calibrations are formally reported to the Quality Department. If classification of instruments is not used, all out-of-tolerance calibrations must be investigated for the effect on product. If the instruments are classified, and classifications are approved by the Quality Department, the investigation is performed only for Critical instruments. Of course, the Calibration Department should investigate all out-of-tolerance conditions, but the release of product would not be held up due to an unnecessary investigation.

CHAPTER SUMMARY

In this chapter we covered the What, Why, Who, and How as an introduction to Calibration. We’ve covered some definitions and concepts that calibration technicians need to be familiar with. It should be emphasized that not all of these concepts are applicable to your facility. Although it would be convenient if we all ran our calibration programs exactly the same way, it just isn’t so. Most of what will be presented in this book are examples that do not fit every situation.

REVIEW QUESTIONS

1. Match the term on the left with the definition on the right.

- | | |
|-----------------------|--|
| ___ Calibration | A. permissible deviation from specified value |
| ___ Instrument Range | B. upper and lower values specified for facility |
| ___ Calibration Range | C. algebraic difference between the upper and lower range value |
| ___ Accuracy | D. adjustment used to produce a parallel shift of the input-output curve |
| ___ Tolerance | E. comparison of instrument to a known value |
| ___ Traceability | F. percent error |
| ___ Zero | G. characterizes the dispersion of the values that could reasonably be attributed to the measurand |
| ___ Span | H. upper and lower values specified by manufacturer |
| ___ Uncertainty | I. measurement related to standards through an unbroken chain of comparisons |

2. Which of the following errors is typically not correctable?

- A. Zero
- B. Span
- C. Linearity
- D. Zero, span, and linearity errors are always correctable

3. Why should a calibration technician have:

- A. Honesty and Integrity?
- B. Attention to detail?
- C. Excellent documentation practices?
- D. Understanding of processes?

4. What are the advantages of performing a field calibration?
Disadvantages?
5. What are the advantages of performing a bench calibration?
Disadvantages?
6. What are the advantages of performing a loop calibration?
Disadvantages?
7. What are the advantages of performing an individual instrument calibration? Disadvantages?
8. What are the advantages of classifying instruments by their “importance/criticality” to a process?
9. Arrange the traceability hierarchy below, beginning with lowest level and ending with the highest. ____, ____, ____, ____, ____
 - A. Primary Standards
 - B. Working Standards
 - C. Process Instrument
 - D. NIST (or recognized national standard)
 - E. Secondary Standards