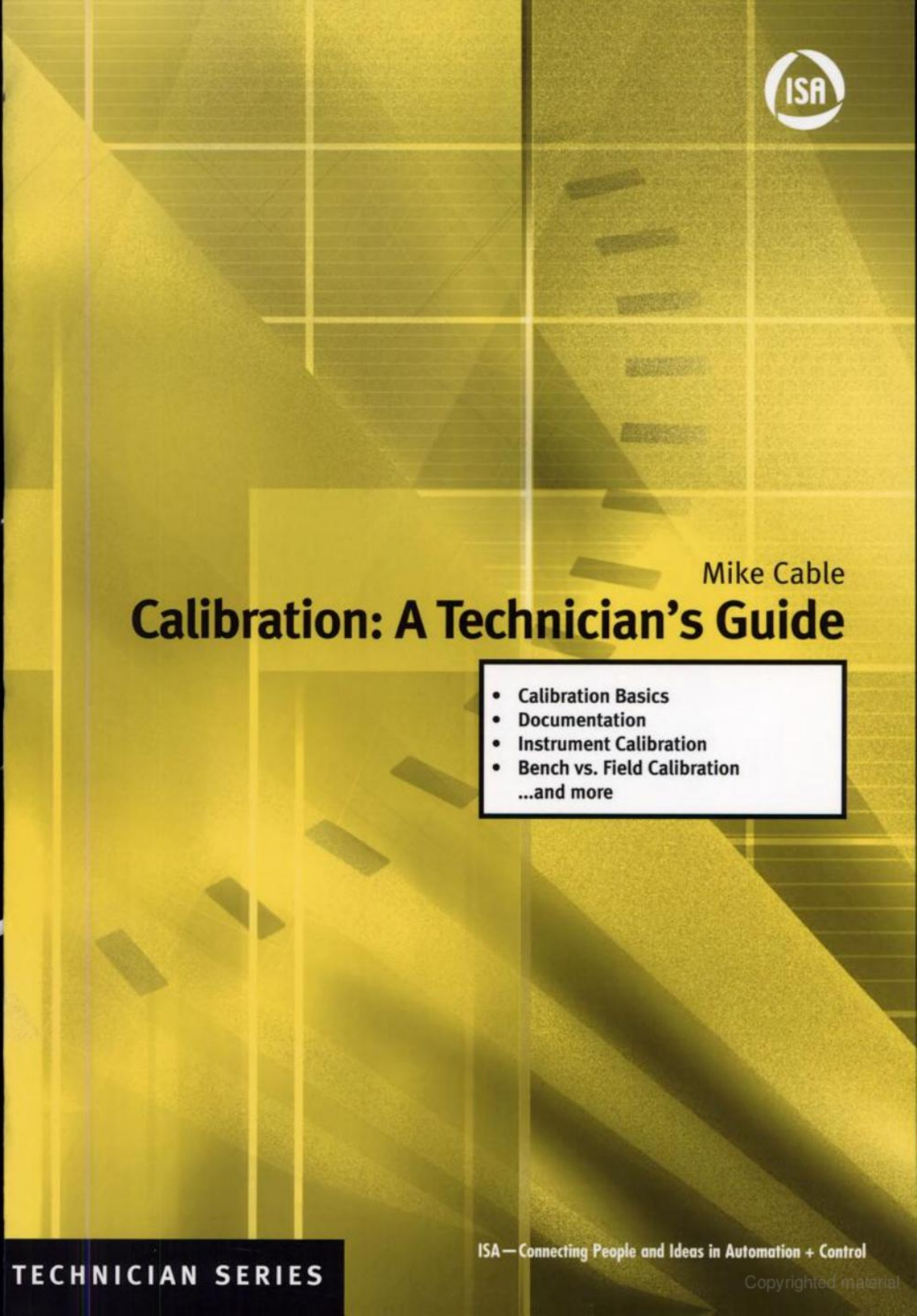

Mike Cable

Calibration: A Technician's Guide

- Calibration Basics
- Documentation
- Instrument Calibration
- Bench vs. Field Calibration

...and more

TECHNICIAN SERIES

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TABLE OF CONTENTS

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Michael Cable is a Level 3 Certified Control System Technician. He is currently the Validation Manager at Argos Therapeutics in Durham, NC where his responsibilities include managing the Calibration Program. Michael started his career as an Electronics Technician in the Navy Nuclear Power Program, serving as a Reactor Operator and Engineering Watch Supervisor aboard the USS Los Angeles submarine and then at the AIW prototype in Idaho Falls. After leaving the Navy, he started his civilian career at Performance Solutions performing technical services for the pharmaceutical industry. His 11 years there was highlighted by an assignment to Eli Lilly Corporate Process Automation managing Instrument Qualification projects and then starting up a Calibration Services division within Performance Solutions. His practical expertise in instrumentation and controls led him to his current career path in Validation, which has been his main focus for the last 7 years.

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INTRODUCTION

ISA's Certified Control System Technician (CCST) program requirements were developed based on a Job Analysis Report initiated by ISA – The Instrumentation, Systems, and Automation Society and Instrument Technicians Labor-Management Cooperation Fund. Response to the survey used to validate the Job Analysis Report indicated that ***calibration*** was the most important, most critical, and most frequently performed of all seven domains for each of the three levels of certification. This is not to minimize the importance of the other six domains, because each is important to all technicians. However, it is obvious that calibration is what most of us do every day. The purpose of this book is to serve as a:

- Study guide for the Calibration domain in CCST certification.
- Reference for technicians who perform process instrument calibrations.
- Reference in the classroom for students pursuing studies related to instrumentation.

This text is applicable for control system technicians performing maintenance and calibrations within the process industry. Although most of the principles would apply, this is not meant for metrologists performing calibrations of test standards in a standards laboratory.

Mike Cable

1

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 ±5°C; available test equipment is capable of ±0.25°C; and manufacturer's stated accuracy is ±0.25°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 ±1°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 ±0.25°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 ±1°C to the process instrument, it is less likely that our calibration performed using that standard is compromised.

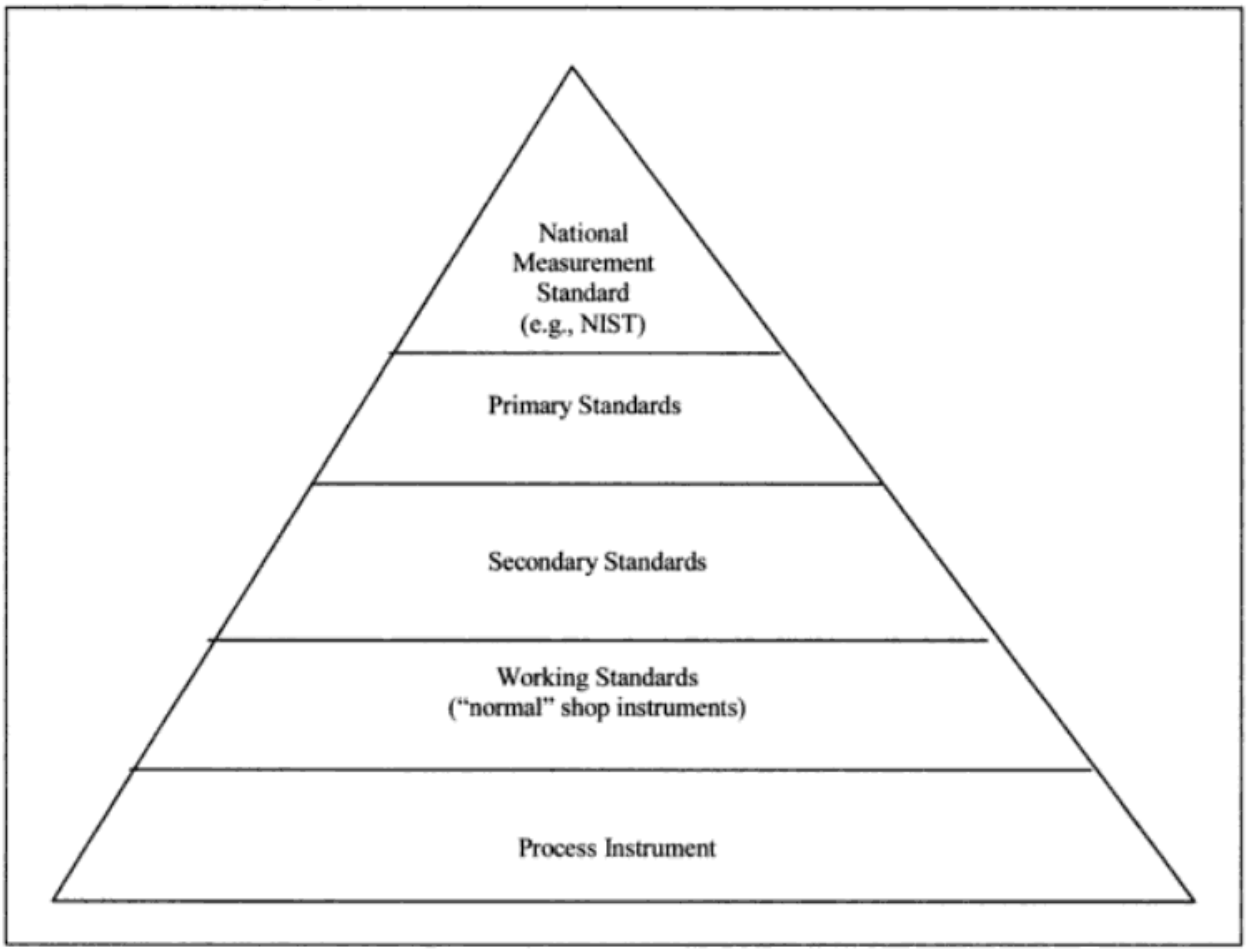
The out-of-tolerance standard still needs to be investigated by reverse traceability of all calibrations performed using the test standard. However, our assurance is high that the process instrument is within tolerance. If we had arbitrarily assigned a calibration tolerance of ±0.25°C to the process instrument, or used test equipment with a calibration tolerance of ±1°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

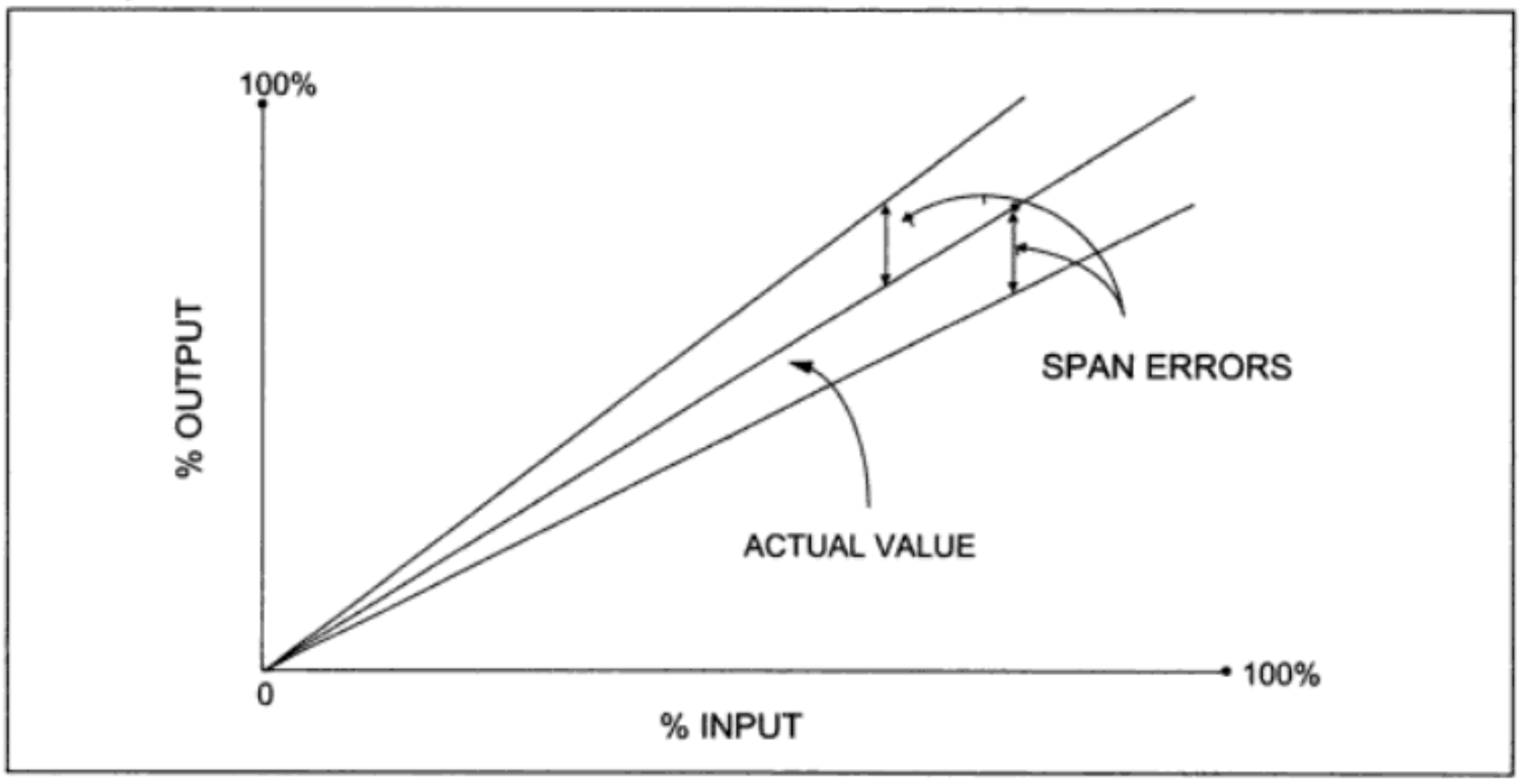


FIGURE 1-3.
Zero Error

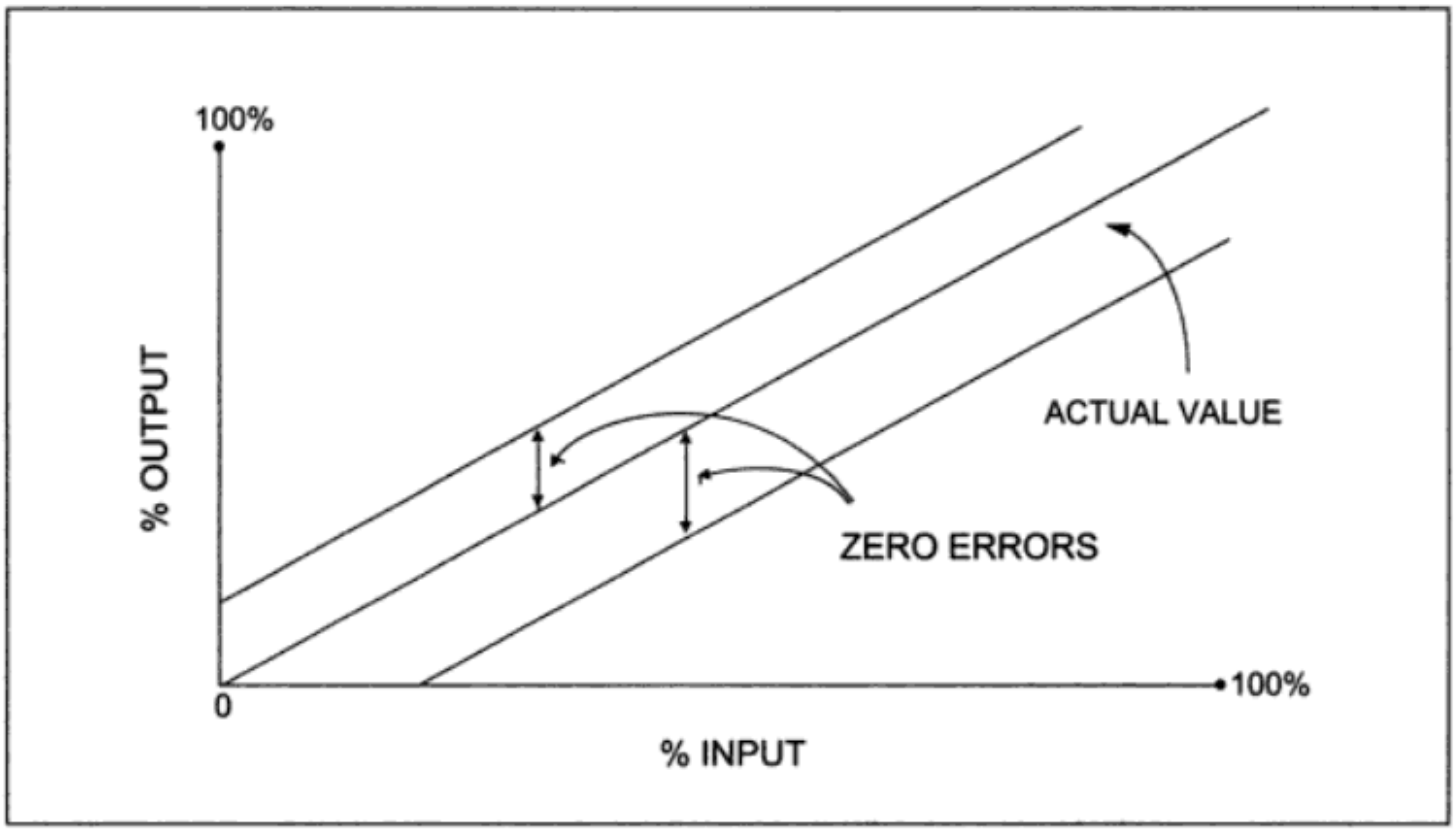


FIGURE 1-4.
Combined Zero and Span Error

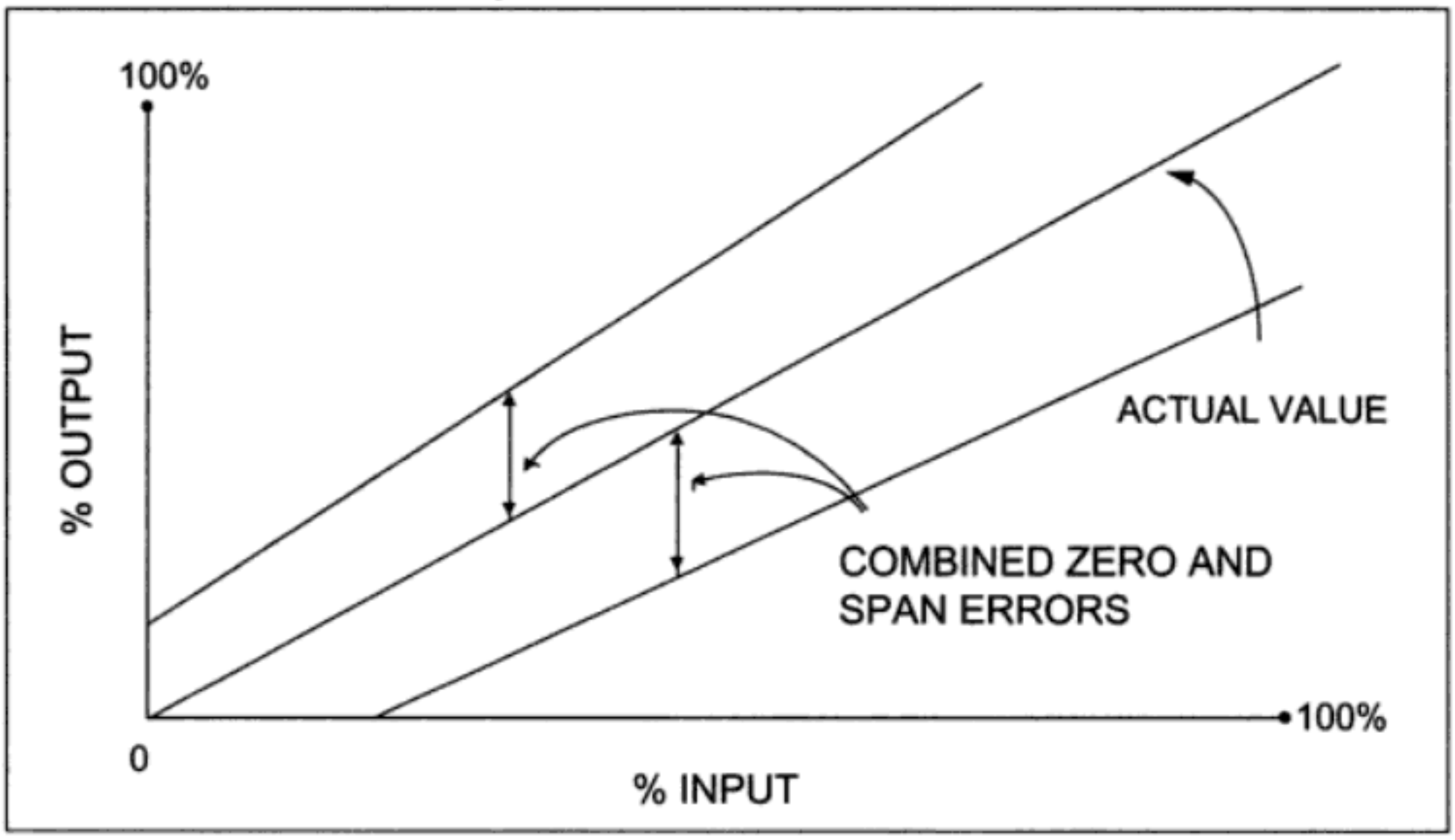
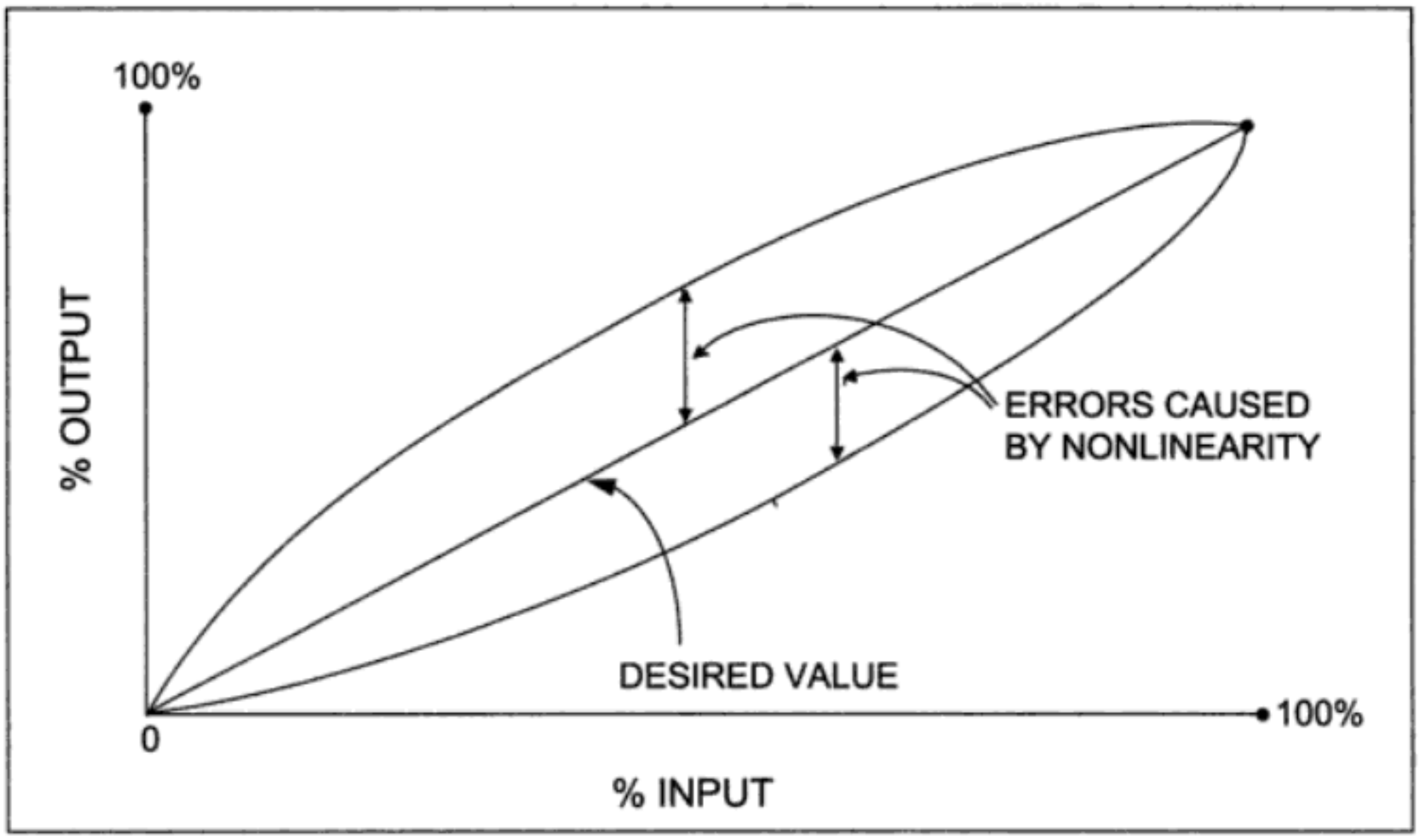


FIGURE 1-5.
Linearization Error



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
___ Instrument Range
___ Calibration Range
___ Accuracy
___ Tolerance
___ Traceability
___ Zero
___ Span
___ Uncertainty

A. permissible deviation from specified value
B. upper and lower values specified for facility
C. algebraic difference between the upper and lower range value
D. adjustment used to produce a parallel shift of the input-output curve
E. comparison of instrument to a known value
F. percent error
G. characterizes the dispersion of the values that could reasonably be attributed to the measurand
H. upper and lower values specified by manufacturer
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

2

DOCUMENTATION

After completing this chapter, you should be able to:

List the fundamental elements of a calibration procedure.

List the fundamental elements of a calibration data sheet.

Define the relevant calibration information contained in the following resource documents: P&ID, Loop Diagram, Instrument Specification Sheet, Project Specifications, and Manufacturer's Specifications.

List the resources for determination of initial calibration frequency for an instrument.

Identify safety considerations relating to calibration.

Describe the use of calibration status labels and what information is required on each.

Because of quality system requirements throughout industry, documentation has become as important as the actual performance of a calibration. This chapter will summarize documentation that all calibration technicians should be familiar with. Another ISA text, *Instrumentation and Control Systems Documentation*, details the documentation mentioned in this chapter, and more.

The accuracy and reliability of instrumentation in a facility is maintained through the development and implementation of a quality calibration program. In addition to inventorying instruments, determining calibration parameters and intervals, and purchasing appropriate test standards, a calibration program includes written procedures for performing calibrations. The level of detail contained in calibration procedures can vary considerably—from a generic procedure used to calibrate an instrument type to a very specific procedure used to calibrate one particular instrument. Different types of calibration procedures are discussed below and examples of each are included in Appendix A-4.

Technical Manual procedure: Typically, a manufacturer's technical manual is provided for each similar model of instrument. Calibration instructions for the instrument are usually given in the technical manual. These instructions can be adopted or adapted as the calibration procedure for the applicable instruments. Most often, the manufacturer's calibration procedure is used to develop a company calibration procedure approved by management and the quality department. However, the actual technical manual procedure may be used or referenced as the calibration procedure if this practice is approved.

TABLE 2-1.
Using Calibration Procedures from a Technical Manual

ADVANTAGES	DISADVANTAGES
Very little time/resources required to develop procedures	Does not contain all necessary elements of a calibration procedure
Technically accurate and detailed instructions for the specific instrument	Applies to instrument only, not taking into account application/process

Generic procedure: Generic calibration procedures can be developed for each instrument type. For example, one procedure could be developed for Electronic Pressure/Vacuum Transmitters and another procedure for Pneumatic Temperature Controllers. You could even go more generic and develop a procedure for Pressure Instrument Calibration, which would include gauges, transmitters, etc. for pressure, differential pressure, and vacuum. Generic procedures should recommend using the manufacturer's technical manual to perform any necessary adjustments.

TABLE 2-2.
Generic Calibration Procedures

ADVANTAGES	DISADVANTAGES
Limits number of procedures to a manageable level	Inconsistent methods by different technicians using same procedure
Can be a good first step for new facility start-up until more effort can be devoted to procedure development	Inexperienced technicians need more detail

Specific procedure for an instrument or a manufacturer/model: In most facilities, some calibration procedures will have to be very specific to particular instruments. In some cases, specific detailed procedures are required for each instrument. Analytical instruments for such parameters as conductivity (resistivity), oxygen, and lab instrumentation typically require specific procedures for each type due to the unique differences in the way each is calibrated. Also, if your generic procedure for a particular pressure instrument does not adequately address the proper method, a specific procedure should be developed. Obviously, if safety could be compromised by using an inadequate generic procedure, a new procedure addressing the specific safety issues must be developed.

TABLE 2-3.
Specific Calibration Procedures

ADVANTAGES	DISADVANTAGES
Calibrations are performed the same way by all technicians	Increases resources required to develop, maintain, and track procedures
May take into account the effect on process	
Technically accurate and detailed instructions for the specific instrument	

Some "old school" technicians initially dislike the use of calibration procedures. They say, "We've always done it this way and never had any problems. Now we've got all this paperwork, it's a wonder we can get any actual work done." Well, in today's regulated environment, you'll be out of business if you don't have a documented calibration program in place. Your customers must be assured of a certain quality product based on parameters you said you could maintain. Most of those assurances are provided from accurate process instrumentation. It has been demonstrated that instrument accuracy deteriorates during use. The only way to keep track of accuracy at any given time is to verify, adjust, and document the calibration data.

2.1 CALIBRATION PROCEDURE CONTENT

What information should be included in a calibration procedure? First, the format should follow the format required by your company procedures. Also any governing documents, such as the Calibration Policy, and any applicable procedures subordinate to the Calibration Policy must be followed.

The calibration procedure typically includes most or all of the following sections:

- *Purpose*: Clearly states the reason for the procedure such as: "The purpose of this procedure is to provide standardized instructions for the calibration of temperature instruments."
- *Scope*: Clearly states to what and to whom the procedure applies such as "This procedure applies to the calibration of all analog pressure gauges at the ABC Company calibrated by employee and contract technicians."

  Note: The purpose and scope can be combined into one section of the procedure. The information in these sections is typically obvious to those of us who perform calibrations, but the managers need this so they know what they're approving.
- *Definitions*: Contains brief descriptions of key terms, as applicable, for clarity. Acronyms and abbreviations used in the procedure are noted in this section to document their meaning throughout the text.
- *References/Attachments*: Identifies other documents, including attachments, that are required to be used in conjunction with the procedure, or allow the user to gain further information regarding the procedural content.
- *Test Equipment/Materials Required*: Identifies the test equipment and materials required to perform the procedure. Listing specific test equipment in this section helps to ensure uncertainty requirements are met and/or the desired accuracy ratio is achieved, particularly if the minimum tolerance achievable is specified in the Scope or Title of the procedure. Note that if the specified test equipment is not available, the technician must notify the supervisor prior to performing the calibration.
- *Safety*: Provide information on potential human health hazards and potential hazards to the facility, equipment, or process. All Safety Work Permit requirements and Material Safety Data Sheet (MSDS) references are included in this section.
- *Prerequisites/Initial Conditions* (optional): Provides any conditions that should be met prior to performing the calibration, such as tank drained, controller in manual, or system shutdown. Alternatively,

these conditions can be included in the test procedure and/or notes printed on the calibration data sheet.

- *Test Procedure*: This is the meat of the procedure which outlines the procedure in a clear, concise, step-by-step manner. If any steps of the calibration procedure cannot be performed as specified, the technician must return the instrument to a safe condition and notify the supervisor.
- *Acceptance Criteria*: The pass/fail criteria may be included in the Test Procedure section or as a separate step at completion, evaluating the results obtained against the tolerances specified.
- *Approvals*: The author and approval signatures or approval authority should be included on each calibration procedure.

As you can see there is a lot of flexibility in what information is included in the calibration procedure and where the information is located in the procedure. Much of this depends on the culture at your facility and experience level of the technicians. Personally, I like to develop good generic procedures with the instrument specifics printed on the calibration data sheet used to record calibration data. There are some example procedures in the reference section. Some comply with what has been described above, some do not.

2.2 CALIBRATION DATA SHEETS

(See Examples in Appendix A-4)

You may refer to this as something else, but what we're talking about here is the form where the as-found and as-left calibration data is recorded when a calibration is performed. As of now, most calibration data sheets are still hardcopy, usually printed out from a calibration software package. Some are still totally manual with no pre-printed information, and that's OK, it works. We are seeing increased use of paperless calibrations where the data is either automatically collected by a documenting calibrator or manually entered into a handheld device as an electronic record. In any case, the following information should be included as part of a calibration data sheet:

- *Instrument Tag Number/Instrument Identification Number*: This is a unique identifier or unique combination used as the main tracking number for each instrument. In most cases the tag number is the

P&ID tag number if applicable (P&IDs are discussed later in this chapter). If the instrument is not associated with a P&ID, there should be some consistent tag number system at your facility that utilizes the ISA-5.1-1984-(R1992) standard.

Several facilities use an additional identification number which is sequentially assigned as an additional tracking number. The tag number references the instrument location within a system, and the instrument identification number stays with the instrument. This way the history of any instrument installed in the instrument location (Tag Number) is traceable and the history of any instrument is traceable. Many instruments stay in the same location for the life of the equipment, in which case this is not as important. But, failures occur and instruments need to be replaced. In other instances, spares are installed temporarily to keep a process running when an instrument is removed for calibration. This traceability is important, for example, in a pharmaceutical facility that produces penicillin. Any instrument removed from a penicillin manufacturing area cannot be used in any other manufacturing area. The instrument identification number used to track where an instrument has been is a useful tool in ensuring that instrument is not installed where it shouldn't be. Even if you don't have similar needs, it's good practice to use both types of identification numbers.

- *Nameplate Data*: The *manufacturer*, *model number*, and *serial number* should be listed on the Calibration Data Sheet.
- *Calibration Range* and *Calibration Tolerance*: This defines the upper and lower limit used for calibration. Ideally, this is the input and output range, if applicable. For example, a good format for the calibration range of a temperature transmitter would be 0-to-100°C = 4-to-20 mA with a calibration tolerance of ±1.0°C/±0.16 mA. As we saw in Chapter 1, the calibration range is not always the same as the instrument range or capability of the instrument.
- *Location*: Be as specific as possible about location of the instrument. You don't want your new technician wasting hours searching.
- *Calibration Procedure Number*: This is the calibration procedure that is used to perform the calibration. In some facilities, the entire calibration procedure is printed on the calibration data sheet.

- *Last Calibration Date*, *Calibration Due Date*, and *Calibration Interval*: This information should be included to ensure the calibration is being performed periodically as required.
- *As-found data* and *As-left data*: Relates the test points specified with the corresponding test standard value. If all as-found data is within tolerance and no adjustments are made, the as-left data would be N/A or the same as the as-found data. Note: Every effort should be made to record as-found data for failed instruments prior to making any adjustments, in order to provide the most data for evaluation.
- *Test Standards*: Record the unique identification of any test standards used to perform the calibration and, if required by procedure, record the calibration due date of the standard(s). It would be best to record this prior to beginning the calibration to ensure each standard is within its calibration periodicity (but, of course you checked this when you obtained the standard from the shop). The most important reason for documenting the test standards is for reverse traceability in case a standard is found to be out of tolerance. If a test standard is found out of tolerance on its next calibration, it is critical that any calibration performed using that standard since its last calibration is known and evaluated to determine a course of action.
- *Comments*: The technician needs someplace to record any comments or observations.
- *Technician Signature* and *Date of Calibration*
- *Supervisor or Reviewer Signature* and *Date*

Example Calibration Data Sheets are included in Appendix A-4. In addition, some example calibration procedures include a data sheet as an attachment.

2.3 P&IDs (See Example in Appendix A-1)

Process/Piping and Instrument Diagrams/Drawings (P&IDs) are drawings that provide a detailed overview of a process system. They include major components, utilities, flowpaths, supporting equipment, and instrumentation. Although P&IDs are commonly used throughout industry, there is not yet a "standard" P&ID. Process Industry Practices (www.pip.org) has developed a P&ID practice; however PIP is not a developer of standards. Draft-Standard-for-Trial-Use, ISA-DSTU-5.07.01, Piping and Instrumentation Diagram Documentation Criteria, was issued in May 2002. ISA-DSTU-5.07.01 is the result of a cooperative effort between ISA (SP5.7) and Process Industries Practices (PIP) by which ISA will develop an American National Standard covering the requirements, design, and graphic elements of that class of engineering drawings called a P&ID, or Piping & Instrumentation Diagram. ISA-DSTU-5.07.01 is based on existing PIP Practice PIC001.

ISA standards ISA-5.1-1984-(R1992), *Instrumentation Symbols and Identification*, and ISA-5.3-1983, *Graphic Symbols for Distributed Control Shared Display Instrumentation, Logic, and Computer Systems*, are the most generally accepted guides for developing symbolism for instrumentation and control systems.

From the P&ID of a particular system, a technician can determine pertinent information about the instrumentation and controls applicable to performing calibrations and understanding the system operation. The most important of these include:

- Components of an instrument loop
- Functional identification
- Methods of signal transmission (pneumatic, electronic, hydraulic, software link, etc.)
- Controller input(s) and output(s)
- Control valve characteristics (fail position, direct/reverse acting)
- Flow sensor types

P&IDs are also used to organize project documentation. Using P&IDs as the base for all information in a large project provides a single reference point for data provided on other documents. This makes sense since P&IDs are used to define system boundaries. It is very important that P&IDs are controlled and maintained up to date. During start-ups the "master" P&IDs are marked up and highlighted to reflect the state of a system at any time. If the technician discovers any discrepancy at any time, the technician must take the responsibility to ensure the controlled drawing is properly revised.

An example of a P&ID is in Appendix A-1. Let's look at the P&ID and see what we can determine about the temperature loop for this process.

We can see from the P&ID that the temperature loop includes TE-300, TT-300, TIC-300, TY-300, and TV-300. Using ISA-5.1 as a reference, we know that the TE is a temperature sensor. We do not know if the temperature sensor is an RTD or thermocouple. That would be determined from the specification or physical inspection. The TT is a temperature transmitter that provides the only input to TIC-300. The TIC is a shared display, shared control temperature-indicating controller. The TY is not as obvious if you're not familiar with the use of this symbol. If you think about it though, you see that the TY is between the electronic output of the TIC and the pneumatic input of the valve, TV. Since the "Y" in TY refers to relay, compute, or convert, according to Table 1 of ISA-5.1, the TY must be a conversion device in the temperature loop. Most likely the device is an I/P transducer which converts a 4-to-20 mA signal from the TIC to a 3-to-15 psig signal for the valve. The TW in the loop is a temperature well, or thermowell, that provides a physical boundary between the temperature sensor and the process.

Side note**:** The thermowell is not a necessary component in the signal conversion of the temperature signal or control. However, because the thermowell consists of a specified thickness of metal it will slow down the response time of the temperature signal. It is also very important to ensure the temperature sensor is the correct length to make contact with the end of the well. Otherwise the air gap will cause an inaccurate reading of the actual process temperature.

2.4 LOOP DIAGRAMS (See Examples in Appendix A-2)

A loop is a combination of interconnected instruments that measures and/or controls a process variable. An instrument loop diagram is a composite representation of instrument loop information containing all associated electrical and piping connections. Instrument loop diagrams are developed in accordance with standard ISA-5.4-1991, *Instrument Loop Diagrams*. Example loop diagrams are included in the Reference Section, Appendix A-2. The minimum content requirements include:

- Identification of the loop and loop components
- Point-to-point interconnections with identifying numbers or colors of electrical and/or pneumatic wires and tubing, including junction boxes, terminals, bulkheads, ports, and grounding connections
- General location of devices such as field, panel, I/O cabinet, control room, etc.

- Energy sources of devices
- Control action or fail-safe conditions

Additional content requirements, format, and examples are included in ISA-5.4-1991.

A formalized loop check should be documented prior to placing any loop in service. This formalized program should include verification of installation against the loop diagram and simulation of signals to verify output responses and indications throughout the range. Why is this important? A significant percentage of instrument loops have some problem, which may result in hidden failures. For example, a temperature transmitter output wired to a programmable logic controller (PLC) analog input provides a temperature display on an operator interface. The transmitter is calibrated from 0-100°C to provide a proportional 4–20 mA output. If the PLC programmer writes the code for this input as 0-150°C for a 4–20 mA input and a loop check is not performed, an inaccurate displayed value will go undetected. Other typical problems found and corrected by performing loop checks include wiring connected to the wrong points, ground loops, and broken wires. Loop checking is another of the CCST domains and is covered in more detail in another ISA Technician Guide.

2.5 INSTRUMENT SPECIFICATION FORMS

(See Examples in Appendix A-3)

Instrument specification forms contain the information necessary to obtain vendor quotes and purchase instrument devices. ISA-TR20 Specification Forms include device specifications for many temperature, pressure, level, flow instruments in Microsoft Word format. The information included on each form is specific to the instrument type but typically includes dimensions, materials of construction, design temperature/pressure, connection sizes, ambient conditions, indicator detail, instrument ranges/tolerances, etc. Examples of instrument specifications are included in the reference section, Appendix A-3. When instruments are received from the vendor, each should be verified against the specification to the maximum extent practicable. This should be documented using a formalized receipt verification process.

For facilities that do not have instrument specification forms from the system design, these forms can be developed using ISA-TR20 or in accordance with company procedure. Some calibration departments develop their own forms to specify the information needed to perform calibrations. These specifications should be approved by users and the Quality Department to ensure process and quality requirements are considered. An example of this form is included at the end of Appendix A-3.

2.6 PROJECT SPECIFICATIONS

Any new manufacturing facility or large expansion project will have a set of project specifications. They include architectural, plumbing, mechanical, electrical, and instrumentation specifications, etc. For instrumentation, the project specifications are usually general, but include content the technician should be aware of, such as:

- Instrument tagging requirements
- Size and type of pneumatic tubing
- Approved methods of mounting instruments
- Wire labeling conventions
- Intrinsic safety standards

For some facilities, the project specifications may include detailed instrument specification forms and an original master instrument list. Although the calibration technician is not usually installing the devices, any discrepancies observed should be brought to the attention of a supervisor.

2.7 MANUFACTURER'S SPECIFICATIONS

In the manufacturer's technical manual or product literature, there is almost always a specification section. Although most manufacturers provide very good specifications, they can vary from inadequate to overly complex. Understanding what the manufacturer's specifications mean is important to purchasing an instrument acceptable for the process requirements and the technician maintaining the instrument. The most important specification for the calibration technician is the instrument range and accuracy. The range capability of the instrument is usually understandable; accuracy is another matter. For example, accuracy may be specified as 0.25%. What does this mean? Is it 0.25% of the range or the reading? For the calibration of a 0-100 psig pressure transmitter at 20 psig, this can mean the difference between 0.25 psig and 0.05 psig. In addition, the specified accuracy is usually different at different ranges of the instrument, varying ambient conditions, and may not even be referred to as accuracy. The lesson is, if you're not sure, ask a technical resource from the manufacturer what the specification means.

2.8 CALIBRATION INTERVALS

Probably the #1 question asked at calibration seminars is "How do I determine the *initial* calibration intervals?" The answer to this question is difficult at first for someone new to developing a calibration program. It ends up being pretty simple. Initially we try to use a variety of resources which include:

- Manufacturer recommendation
- National Conference of Standards Laboratories Recommended Practice RP-1
- Past experience
- Intervals of similar existing instruments

In reality, it is a combination of all the above, but mostly past experience. As an example, in my experience, electronic transmitters have a calibration interval of 6 months and analog gauges have an interval of a year. Many manufacturers' specifications contain a 6-month stability specification. This stability specification, in effect, only guarantees the accuracy specification for 6 months. Also, electronic transmitters are typically installed in applications that are "more important" to the process. Even though these instruments are more reliable than analog gauges and fail calibration less often, we check the calibration on a more frequent basis. This means we set our calibration intervals based on how much risk we are willing to take. If we wanted an almost 100% assurance that our instruments were within calibration tolerance, we'd have to check the calibration almost every day. Obviously, that would be impracticable. So we assume some risk that every once in a while a calibration is not going to pass. Of course our managers and quality department don't want to hear that, but it happens and we need to educate other disciplines that it does happen.

Don't be alarmed if you calibrate more or less often than described above. It simply means you're willing to take more or less risk based on the process and quality standards at your facility or you have more history to base your calibration intervals on. Of course not all instruments fit into the same category. Some instruments, particularly analytical instrumentation, are calibrated more frequently, even to the point that the user performs a calibration check prior to each use. On the other hand, some instruments may have an interval of two years or more.

Calibration intervals may be adjusted over time. Once several calibrations have been performed, the calibration history of the device may be used to adjust the calibration interval. If the as-found calibration data of a particular instrument does not meet the calibration tolerance, the calibration interval may be shortened. If several instruments with a particular manufacturer/model number are always well within the calibration tolerance, the interval is increased.

2.9 SAFETY CONSIDERATIONS

Obviously, performing calibrations safely is very important. One lapse on safety could cost you or your co-worker your lives. Even if it's not a life lost, minor injuries caused by unsafe work practices are preventable. Safety of the product is also of concern when performing calibrations in a manufacturing environment. There are many resources available from ISA on the topic of safety, including Chapter 1 of *Troubleshooting: A Technician's Guide*, by William L. Mostia. Here are a few things we, as calibration technicians, can do to improve safety in our day-to-day work activities.

- Include specific safety considerations in each calibration procedure. For example, if we know there is a tank that does not have a thermowell installed for the resistance temperature detector (RTD), highlight this fact. Better yet, if possible, get a thermowell installed.
- Keep the shop and work areas clean and free of trip hazards.
- Work with a partner or at least make sure someone knows where you are working at all times.
- Some instruments are always installed at difficult places to reach. If it's possible to install some permanent platform, have it done. Otherwise use safety harnesses, ladders, and lifts properly.
- Technicians may be exposed to lethal electrical voltages. Know what the high voltage areas are, de-energize electrical circuits that are not required, and use proper electrical safety practices

(insulated floor mat, rubber electrical safety gloves, roped off area, safety man outside the area with a rope tied around you).

- Ensure electrical power cords are properly insulated. Ensure equipment is properly grounded.

2.10 CALIBRATION STATUS LABELS

Calibration status labels are used to provide a visual indication of the calibration status of an instrument. Many different label styles are in use throughout industry. The main information that must be displayed showing the calibration status are the Instrument Identification (such as Tag Number, Instrument ID number, or serial number), date of calibration, next calibration due date, and the technician who performed the calibration (initials, employee ID, etc.). An example is illustrated below.

ABC Company – Calibration Status
ID: ______________________
Cal Date: _________________
Cal Due: _________________
Technician: _______________

Other amplifying information may be included on the label or a separate label. Examples include:

- Customized labels with company name and color coded for classification as described in Chapter 1.
- Limited Calibration Label for instruments that are not calibrated throughout the range of the indication. An example of this would be a compound gauge that is not calibrated for the vacuum range because the process does not operate under a vacuum at any time.
- Another example would be an instrument that does not meet tolerance requirements at the extremes, but the process would never operate at these extremes.
- Other labels such as "Do Not Use" or "Calibration Not Required" can be used, if applicable.
- Sometimes tamper-proof seals are used to cover exposed adjustments so that any unauthorized adjustments are detected.

This chapter has summarized the most common documentation required or utilized by the calibration technician. These subjects were not discussed in excruciating detail, because other resources are available. However, it is important to expose technicians to the concepts and provide some examples to help put the big picture together before we start with the actual performance of the calibrations.

REVIEW QUESTIONS

1. List the advantages of each procedure development method below.

    A. Straight from technical manual

    B. Generic procedure for an instrument type

    C. Procedure developed for a specific manufacturer/model or specific instrument in the plant

2. If test equipment with the specified accuracy is not available to perform the calibration, what should you do?

3. If a step of a calibration procedure cannot be followed as specified or a procedure does not exist, what actions would you take?

4. What elements of a calibration data sheet reflect that the calibration is NIST-traceable?

5. For an established facility, what is the most likely resource for determining the calibration frequency of a new instrument?

6. For a new facility, what is the most likely resource for determining initial calibration frequency?

7. What justification can be used to increase the calibration interval (performing calibration less often) of all instruments of the same type?

8. What event(s) can lead to decreasing the calibration interval (performing calibration more often)?

9. Match the resources on the left with content on the right.

___ P&ID	A. Includes general instrument specifications for the facility
___ Instrument Specification Sheet	B. Includes instrument range capability and instrument accuracy
___ Loop diagram	C. Detailed overview of a process system
___ Project specifications	D. Detailed device requirements
___ Manufacturer's Specifications	E. Includes all associated electrical and piping connections

10. What is the purpose of a calibration seal?

11. What is the minimum information required on a calibration status label?

12. When should a Limited Calibration status label be used?

13. What criteria must be met for test equipment to be used for calibration?

3

TEMPERATURE INSTRUMENT CALIBRATION

After completing this chapter, you should be able to:

Describe the different types of temperature sensors, including important advantages and disadvantages of each.

Calibrate the following temperature instrument types (to ISA standards, where applicable) and determine acceptability:

- *Glass and Dial Thermometers*
- *Temperature sensors (RTDs, thermocouples, and thermistors)*
- *Temperature transmitters*
- *Digital temperature indicators and controllers*
- *Temperature switches*

Select proper calibration procedure and calibration data sheet

Select appropriate certified test equipment.

Properly setup/connect test equipment to the Device Under Test (DUT) for calibration.

Properly isolate temperature devices and/or remove from service for field calibration.

Return equipment to service following calibration.

Complete and properly maintain calibration documentation.

3.1 WHAT IS TEMPERATURE?

Anything that moves has kinetic energy, the energy of motion. Atoms and molecules have kinetic energy because they are always moving. The faster a molecule moves, the greater its kinetic energy. Heat is the measure of the total quantity of kinetic energy due to molecular motion in a body of matter. Temperature measures the intensity of heat due to the average kinetic energy of the molecules.

3.2 TEMPERATURE SENSORS

There are several different types of sensors used to measure temperature. Some of the more common sensor types are summarized in this section.

Thermocouples

Thermocouples are very common due to the ruggedness, low cost, response time, and relatively good accuracy, but mostly because of the versatility. Thermocouples can be used over a wide range of temperatures, whereas RTDs are useful only over a certain temperature range. Thermocouples are based on the principle that joining two dissimilar metals will produce a voltage signal proportional to temperature. Although very commonly used, thermocouples are least understood due to the complexity of different metals used, reference junction, and methods of compensation. The Reference Section of the *Omega Temperature Handbook* provides a very good explanation of the details.

There are several types of thermocouples, based on the types of metals that make up the thermocouple. For example, a Type T thermocouple is made from copper and constantan wires, whereas Type K is made from chromel and alumel. Each type is color coded and, per U.S. standards, the red lead is always negative. Due to the many thermocouple types, a technician must verify the thermocouple type used and ensure the correct reference table and/or test equipment setup is used for that thermocouple type. (For examples, see the reference tables in Appendix A-6.)

Resistance Temperature Detectors (RTDs)

RTDs are most commonly made from platinum, due to its stability and linearity throughout the range of use. However, RTDs exhibit a slower response time to temperature changes than thermocouples. All RTDs have a positive temperature coefficient, which means the resistance increases as temperature increases. The most widely accepted type of RTD conforms to DIN 43760. This RTD has a resistance of 100 ohms at 0°C with a temperature coefficient (α) of 0.00385 (spoken as three-eighty-five alpha).

The alpha coefficient is determined from the slope of the line between 0 degrees C and 100 degrees C and also the resistance of the RTD at 0 degrees C. The alpha is expressed in units of ohms per ohm per degree C where the second "ohms" refers to the resistance at 0 degrees C. For the DIN 43760 RTD, the ohms for 0 degrees C is 100 and the ohms for 100 degrees C is 138.50. The change in ohms for 100 degrees is 38.50. The change for 1 degree is 0.385 ohms. The alpha is 0.385 ohms per degree C divided by the resistance at 0 degrees (100 ohms) which equals 0.003850 ohms per ohm per degree C. The resistance output for an RTD is not perfectly linear, and the ohms for a given temperature cannot be determined from the alpha coefficient alone. The complete equation for the RTD output also includes other coefficients that define the non-linearity.

RTDs are connected electrically in a bridge configuration to offset the effects of lead length resistance. RTDs are purchased as 2-wire, 3-wire, or 4-wire RTDs. Again, the *Omega Handbook* provides a good explanation of the details. The most important thing for a technician to understand is the RTDs must be connected correctly during initial installation and upon completion of calibration. Also the technician must be careful to use the correct RTD table as a reference when performing calibrations.

Thermistors

Thermistors are based on a resistance change in a ceramic semiconductor. Thermistors are much more temperature sensitive that thermocouples or RTDs. This allows thermistors to detect very small changes in temperature which would not be detected by RTDs or thermocouples. Most thermistors have a negative temperature coefficient, which means the resistance decreases as the temperature increases. However, thermistors are very non-linear and therefore must be used over a small range to provide a linear response. Thermistors are also susceptible to drift and are very fragile.

Filled Bulb

Filled-bulb sensors are a closed system filled with a liquid that expands as the temperature increases and contracts when temperature decreases, producing a proportional change in temperature indication or a control valve response.

3.3 SIGNAL CONVERSION

Signal conversion is used to convert the voltage of a thermocouple or resistance of an RTD/thermistor to a signal usable by an instrument system. For example a temperature transmitter may convert the RTD resistance to a 4–20 mA signal for a PLC input or a recording device (or both). A separate signal conversion device is not always used since many devices (controllers, indicators, PLC inputs) can be configured for direct sensor input.

Now that we have some idea of how temperature is sensed, let's look at some examples.

Example Temperature Calibration #1 – Calibration of a Dial Thermometer

A dial thermometer consists of a sensing probe connected to a dial indicator. The temperature sensed causes movement of the dial pointer across a graduated scale. The graduated scale provides an indication over a range of temperatures. The goal of the calibration is to verify that the pointer "points" to the correct value over the range of the instrument. Our example thermometer has a range of 0 to 100°C, and we'll be checking the calibration at 5 points: 0°C, 25°C, 50°C, 75°C, and 100°C.

The test equipment we'll use is a refrigerated temperature bath and a temperature standard. An ice bath could be used to check the 0°C point if a refrigerated bath is not available. An ice bath is prepared by using crushed ice made from distilled water and adding distilled water to make a "slush." It is best to make the ice bath in an insulated container. The ice bath should be adequately mixed just prior to placing the sensor in the ice bath and, if possible, while the sensor is in the ice bath.

In some cases, the temperature bath may have a temperature indication which could be used as the temperature standard. The temperature indication on the temperature bath can only be used as a standard if it has been calibrated itself. It is still not the best practice to use the bath temperature indication as a reference since the location of the sensor is not the same as the device being calibrated. In most cases, a separate temperature standard must be used to obtain the required accuracy ratio (accuracy ratio is discussed in Chapter 1).

To perform the calibration, the thermometer is removed from the system and placed in the temperature bath (or ice bath) at the minimum test point of 0°C. Our temperature standard is also placed in the temperature bath (or ice bath) at the same depth such that the tips of the thermometer and standard are as close together as possible. Once the readings have stabilized, the "as-found" readings are recorded for the temperature standard and the unit under test. No adjustments are made until all "as-found" readings are recorded for all test points. Now we change the temperature bath setpoint to 25°C. (If an ice bath was used at 0°C, move the thermometer and standard to the bath.) Once readings have stabilized, record the "as-found" values for the thermometer and standard on the calibration form. Note that we do not need to record the bath temperature indication, if provided, since this is not our standard and has no bearing on the calibration. Obtain the "as-found" readings for the thermometer and the standard at 50°C bath setpoint, then 75°C setpoint and finally 100°C setpoint.

Now that the "as-found data has been collected, let's evaluate the data. The table below shows our as-found results.

TEST POINT	AS-FOUND DATA		
	TEST STANDARD READING	UNIT UNDER TEST READING	ERROR
0°C	0.12°C	1°C	+ 0.88
25°C	25.08°C	26°C	+ 0.92
50°C	50.17°C	51.5°C	+ 1.33
75°C	74.99°C	76.5°C	+ 1.51
100°C	100.02°C	102°C	+ 1.98

Let's say our calibration tolerance is 2°C and we find the thermometer is adjustable. Some are not adjustable, in which case the thermometer would need to be replaced if the "as-found" data was not within the acceptable tolerance. Since this thermometer has one adjustment using an external screw, how much should we adjust the thermometer? If the process, monitored by the thermometer, normally operates at a specific setpoint, it is recommended to adjust the thermometer to read correctly at that value. If the process operates over the range of the instrument, adjust the thermometer based on the average error such that all readings are as close as possible. In any case, the thermometer should be adjusted such that when you've completed the adjustments all "as-left" data is within the specified tolerance.

We find the process operates at 50°C. Therefore, adjust the temperature bath setpoint to 50°C. Once readings have stabilized, adjust the thermometer to read the same as the temperature standard. Once the adjustment is complete, record the stabilized thermometer and standard reading at each test point as the "as-left" readings. Verify all values are within tolerance and the desired results were achieved. Below is a table of our results.

TEST POINT	AS-FOUND DATA			AS-LEFT DATA		
	TEST STANDARD READING	UNIT UNDER TEST READING	ERROR	TEST STANDARD READING	UNIT UNDER TEST READING	ERROR
0°C	0.12°C	1°C	+ 0.88	0.10°C	– 0.5°C	– 0.60
25°C	25.08°C	26°C	+ 0.92	25.05°C	24.5°C	– 0.55
50°C	50.17°C	51.5°C	+ 1.33	50.13°C	50°C	– 0.13
75°C	74.99°C	76.5°C	+ 1.51	74.91°C	75°C	+ 0.09
100°C	100.02°C	102°C	+ 1.98	99.97°C	100.5°C	+ 0.53

Note: A Calibration Seal should be affixed to the external adjustment to detect any unauthorized adjustment to the thermometer.

Once you actually perform a calibration as described above, you'll see it can be very time consuming to wait for the temperature bath to stabilize at each of the five points (depending on the type of bath used). It may take all day to perform this one calibration. There are several things you can do to increase productivity.

1. Have several thermometers scheduled for calibration at the same time. It is typically the supervisor's job to properly schedule the work, but you can look to see if there are other thermometers due the same month and obtain authorization to calibrate them.
2. If there are other temperature baths available, set up the baths at different temperature setpoints. It is recommended to use the same temperature standard for all test points, but it does not take as long for the standard to stabilize as it does for the baths.
3. Use your spare time waiting during setpoint changes to perform other work.

Example Temperature Calibration #2 – RTD Calibration Check

Although temperature sensors are usually checked as part of a calibration of the connected device, it may be necessary to check a suspect temperature sensor or to verify the accuracy of a new RTD. The principles of this RTD calibration check would apply to any sensor type. The only exception would be a thermocouple calibration check if the test equipment used to read the thermocouple does not have automatic reference junction temperature compensation. All modern test equipment performs the temperature compensation, but it is important to verify. If you perform a thermocouple calibration check and do not have temperature compensation, you'll need a second temperature standard to measure the reference junction ambient temperature and compensate manually.

For this example, let's say we need to check the RTD at five points, from 50°F to 250°F. Just like the thermometer in example #1, we'll need a temperature bath capable of achieving the desired range of 50°F to 250°F, a temperature standard, and a test instrument capable of reading resistance (such as a multimeter or multi-function calibrator). Will we need a refrigerated bath (or an ice bath) like we needed for the thermometer calibration in example #1? Yes, since the minimum test point of 50°F is below normal ambient temperature, we will need a refrigerated bath.

We'll also need the correct RTD table to determine our expected resistance at 50°F, 100°F, 150°F, 200°F, and 250°F. Typically, we would use the applicable RTD table. However it is not unusual for the manufacturer to provide an RTD table specific to an individual RTD. If the manufacturer provides a specific RTD table, it should be added to the documentation file for this device, used for the calibration check of this RTD, and used for the calibration of any device connected to this RTD. For our example, we will use the standard RTD table for our RTD, which is a 100 ohm, platinum, 385 alpha RTD. (Refer to the correct RTD table in Appendix A-6.)

To perform the calibration check, place the temperature standard and RTD in the temperature bath. Adjust the bath temperature to each of the test points. Record the temperature standard reading and RTD resistance at each test point. Fill in the expected resistance readings for the five-point calibration check from the applicable table in Appendix A-6. If you have difficulty, an explanation follows the table.

TEST POINT (°F)	TEMPERATURE STANDARD READING (°F)	CONVERSION TO °C	EXPECTED RTD RESISTANCE (OHMS)	ACTUAL RTD RESISTANCE (OHMS)	ERROR (OHMS)
50	50.0			103.88	
100	100.0			114.70	
150	150.0			125.40	
200	200.0			136.00	
250	250.0			146.50	

First of all, we base our expected resistance values on the actual temperature standard reading obtained, not the test point. We made this easier by using nice even temperature standard readings, which will not be the case in reality. However, since the RTD tables reference temperature in degrees Celsius, we did add a degree of difficulty specifying the test points in degrees Fahrenheit. For the first data point of 50.0°F we must first convert to °C using the conversion °C = (°F - 32) x 5/9, which results in an answer of 10.0°C. The remaining conversions are 37.78°C, 65.56°C, 93.33°C, and 121.11°C, respectively.

For the expected resistances, we can obtain the value for 10°C directly from the RTD table. You should have 103.90 ohms for the expected resistance at 50°F (10°C). The remaining test points are not as simple. They require interpolation. For the 37.78°C data point you must first find the resistances for 37°C and 38°C, which are 114.38 ohms and 114.77 ohms, respectively. Next, find the difference between these resistance values, which is 0.39 ohms in this case. To perform this interpolation, understand that we are basically finding the resistance value, which is 78/100ths of the way between 114.38 and 114.77. This is simply done by multiplying 0.78 x 0.39, and adding the result to 114.38. The expected resistance for 37.78°C is 114.68 ohms.

To find the expected resistance for 65.56°C (100.0°F), multiply 0.56 x 0.38 and add the result to 125.17 ohms. The value for the expected resistance at the 100°F is 125.38 ohms. For 93.33°C, multiply 0.33 x 0.38 and add the result to 135.85 ohms for an expected resistance of 135.98 ohms. For 121.11°C, multiply 0.11 x 0.37 and add the result to 146.45 ohms, for an expected resistance of 146.49 ohms.

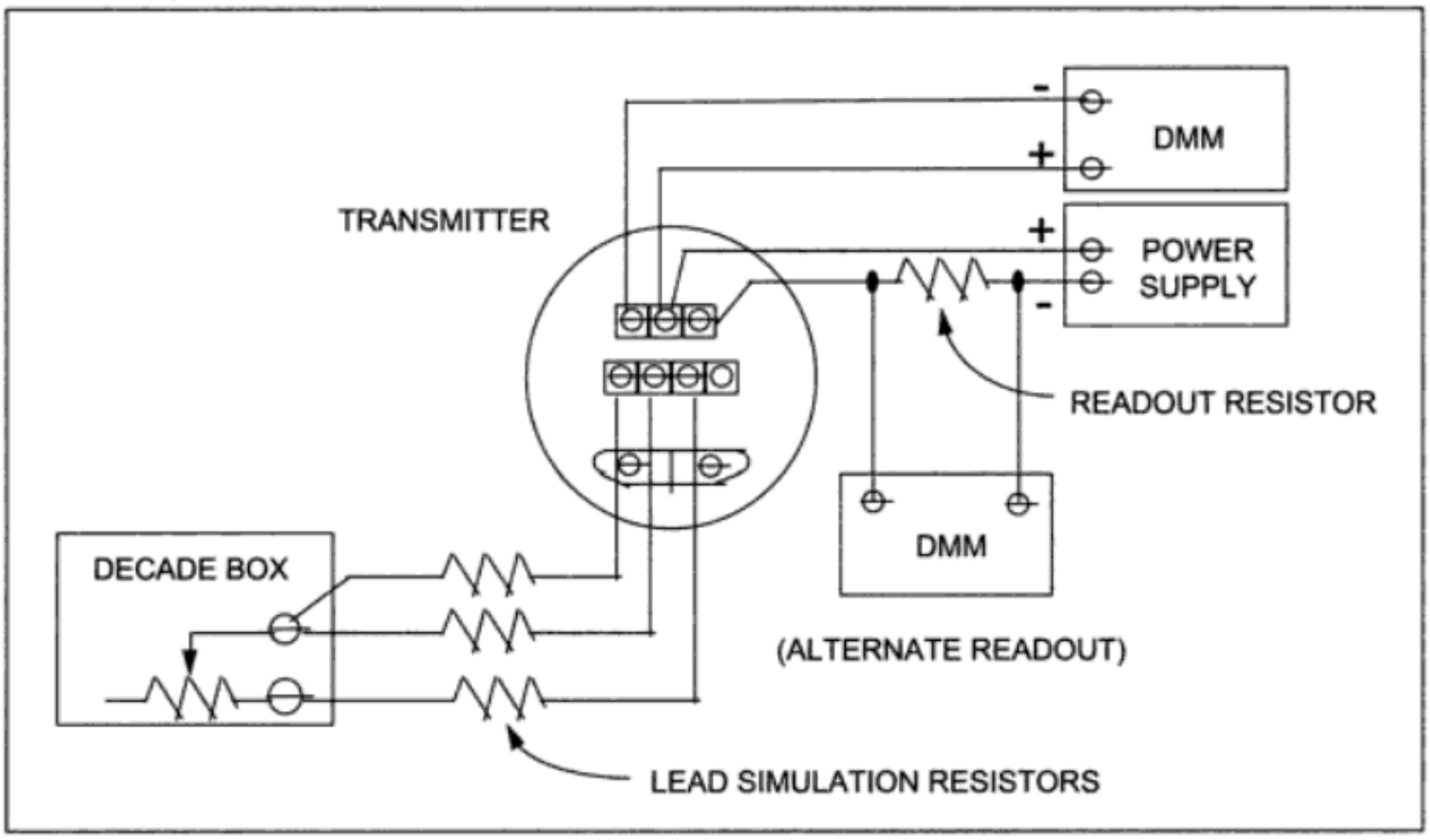
Complete the table. Assuming our allowable tolerance is 0.1% of reading, did our calibration check pass? At the expected resistance of 103.90, the allowable tolerance is 103.90 x 0.001, or 0.1 ohms. The remaining acceptable tolerances are calculated by multiplying 0.001 by expected resistance.

Example Temperature Calibration #3 – Temperature Transmitter

There are two basic methods to calibrate a temperature transmitter in-situ. The first is to calibrate the sensor and transmitter together by placing the sensor in a temperature bath/block and measuring the transmitter output. The second basic method is to disconnect the sensor from the transmitter and use a simulator in place of the sensor. If the sensor is an RTD, a decade box or RTD simulator would be connected to the transmitter input in place of the RTD. If the sensor is a thermocouple, a thermocouple simulator of the correct type would be connected to the transmitter input. Any local or remote indications connected to the transmitter output could be calibrated along with the transmitter as a loop.

It is recommended that, if a loop calibration is performed, the transmitter output should still be measured and recorded. The reason for measuring the transmitter output for a loop calibration is to determine which device, transmitter or indicator, would require adjustment if an adjustment were necessary. Either method, individual instrument calibration or loop calibration, is acceptable depending on your industry practices and procedures. The advantages and disadvantages of each method are discussed in Chapter 1.

FIGURE 3-1.
Temperature Transmitter Calibration Setup (Courtesy Rosemount, Inc.)



For our example let's perform a calibration of TT-300 using a decade box per the calibration procedure SOP-CAL-08, Method B in Appendix A-4. The specification for TT-300 is included in Appendix A-3. Use the information from procedure SOP-CAL-08, TT-300 specification, and RTD Table in Appendix A-6 for 385-alpha to complete the tables below.

TABLE 3-1.
Preliminary Operating Point Check

TEST POINT	TEMPERATURE STANDARD	ACTUAL TRANSMITTER OUTPUT	CONVERTED TEMPERATURE	ERROR
70°C	70.12°C	11.35 mA	68.90°C	-1.22°C

TEST POINT	SIMULATED TEMPERATURE (°C)	INPUT RESISTANCE (OHMS)	EXPECTED TRANSMITTER OUTPUT (mA)	ACTUAL TRANSMITTER OUTPUT (mA)	ERROR
10%	15.0	105.85	5.60	5.50	-0.10 mA
50%	75.0	128.98	12.00	11.88	-0.12 mA
90%	135.0	157.31	18.40	18.27	-0.13 mA

Given the actual transmitter output above, does the transmitter require calibration? If the manufacturer's specification of 0.2% is used, the transmitter requires calibration. If the calibration tolerance is ±1%, which would equate to 1.5°C and 0.16 mA, the instrument is within tolerance, but should be adjusted since it is close. A good rule of thumb is to adjust if the instrument is > ½ the specified tolerance. You should not get in the practice of always performing adjustments to get the instrument calibration "right on," because even performing adjustments can lead to deteriorated performance.

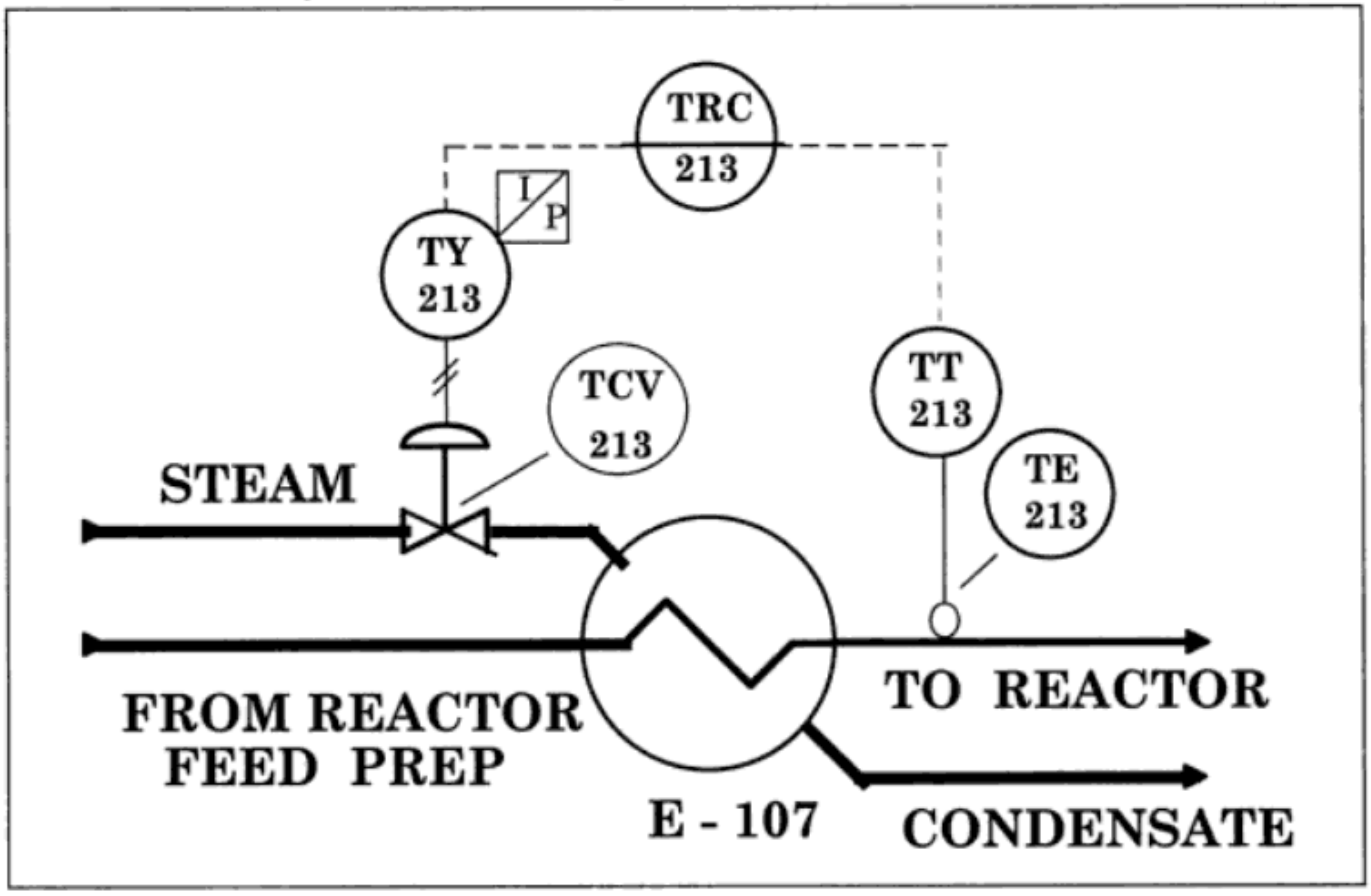
You may be asking yourself why the procedure requires test points of 10%, 50%, and 90%. Zero percent, 50%, and 100% may be the normal test points that you are used to and that is fine. For loops that include an operator interface, the reading may not go below the minimum or above the maximum. Therefore, if the 0% and 100% test points were used, you would not know if the reading was actually below the 0% reading or above the 100% reading.

Example Temperature Calibration #4 – Temperature Controller Loop

A temperature controller can be a stand-alone device or a function of the computer control system, such as a programmable logic controller (PLC) or distributed control system (DCS). If the temperature controller is a function of a computer control system, it is typically not calibrated because it is not really a device subject to going out of calibration. A stand-alone controller usually has many capabilities such as multi-function configuration, alarm setpoints, analog and on/off outputs. For our example, we'll assume we have a Moore 352 controller configured for 4-20 mA input with a corresponding display of 0 to 100°C. The controller is also configured for a low alarm of 30°C and a high alarm of 40°C. The 4-20 mA output is supplied to an I/P (current-to-pneumatic) transducer for control of a steam valve.

For our calibration we only need to concern ourselves with the controller itself. The temperature transmitter that supplies the mA input is calibrated separately. The I/P transducer is also calibrated separately. It's a good idea to have the calibration of all loop components scheduled together. You could also perform a calibration for the entire loop as previously discussed, if desired. However, to start with it is very important that the control system technician understands how the controller interfaces with the process. First of all, the system must be in a state which will allow the safe performance of the calibration. The system controlled by this controller should be shut down and the controller placed in manual operation. If the controller remained in automatic during the calibration, the simulated signals would cause output responses which could be detrimental to equipment and process.

FIGURE 3-2.
Control Loop on P&I Drawings



Once the system is in a safe condition and the controller is placed in manual, we can disconnect the controller input leads and connect a milliamp simulator to the input. To perform the calibration, adjust the milliamp simulator to the desired setpoints and record the controller display. If the display requires calibration, follow the manufacturer's procedures for calibration. For microprocessor based instruments, the calibration is usually not performed by turning a potentiometer, but rather adjusting the input to a pre-determined value and pushing buttons so the microprocessor can make the adjustments.

Once the display is properly calibrated, it's a good idea to verify alarm setpoints and control output action. This is not required and many calibration procedures would not include it. To perform the alarm checks, the milliamp simulator is adjusted as necessary to determine the temperature at which the low and high alarms trip and reset. To check the controller output for proper operation, adjust the milliamp simulator above and below the setpoint safely to verify the proper output action is occurring.

Example Temperature Calibration #5 – Temperature Switch

A temperature switch is a device that senses temperature and changes state at the programmed or adjusted setpoint. A temperature switch usually has at least one set of normally open (NO) and one set of normally closed (NC) contacts, but may have only a NC contact, a NO contact, or more than one set of each. NO and NC refer to the state of that contact with the switch de-energized. The tricky part of calibrating a temperature switch is to know whether the switch should "trip" with increasing or decreasing temperature. Typically, a high temperature switch would "trip" with increasing temperature, and vice versa.

Basically the calibration of the switch is checked by placing the sensor in a bath and measuring across the applicable contact with a multimeter. The bath temperature is increased/decreased to the setpoint. The multimeter will read the change of voltage or resistance when the switch changes state. In other words, the multimeter will read 0 volts with the switch closed and supply voltage with the switch open. If the contact is a "dry" contact (no voltage), the multimeter will read close to 0 ohms with the contact closed and infinite ohms with the switch open. (Hint: You may want to disconnect and electrically insulate the leads to check the switch by itself. This removes any parallel resistances and external circuits from interfering. As an alternative, use the remote indication as confirmation of proper switch operation. Be cautious of circuit and display time delays.)

REVIEW QUESTIONS

Situation for Questions 1 – 10: TT-300 is installed in a process tank, which is currently in production. This is the first calibration after initial startup. Use the references in Appendix A to answer the following questions.

1. What is the correct calibration range and manufacturer's specified accuracy for TT-300? (Appendix A-3)

2. Select the correct procedure(s) that could be used for this calibration of TT-300? (Appendix A-4)

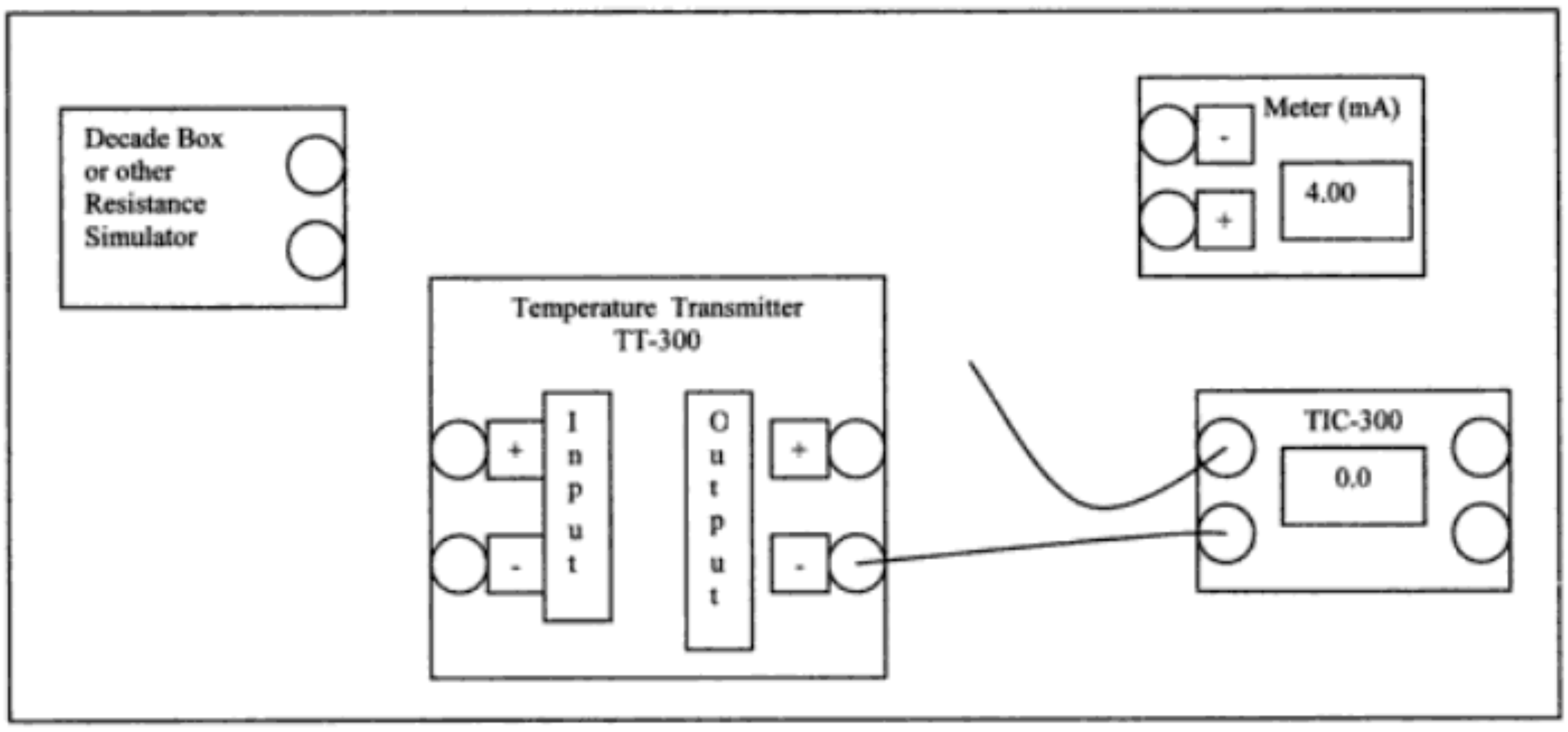
3. What local/remote indications should be recorded during calibration of TT-300? (Appendix A-1)

4. What must be done prior to removing RTD for calibration of TT-300? (initial conditions of standard operating procedure, SOP)

5. What are the correct resistance values to input for 10%, 50%, and 90%? (refer to the correct RTD table in Appendix A-6)

6. What are the expected transmitter output values for the resistance inputs from step 5?

7. Indicate the correct test equipment hookup for calibration of TT-300.



8. Assume a calibration tolerance of ± 0.5°C/0.05 mA. With the results indicated, what instrument(s) in the loop require(s) adjustment?

% INPUT	mA OUTPUT	TIC-300 INDICATION
10%	5.70	15.9
50%	12.10	75.9
90%	18.50	135.9

9. What type of error is indicated by the results of question 8?

   A. Zero error
   B. Span error
   C. Zero and Span error
   D. Linearity error

10. Following adjustment, all "as-left" data is within tolerance. What must be performed to place the instrument loop back in service?

Situation for questions 11 – 15: You will be performing an initial calibration of TT-200 on the bench, prior to installation. Use the references in Appendix A to answer the following questions.

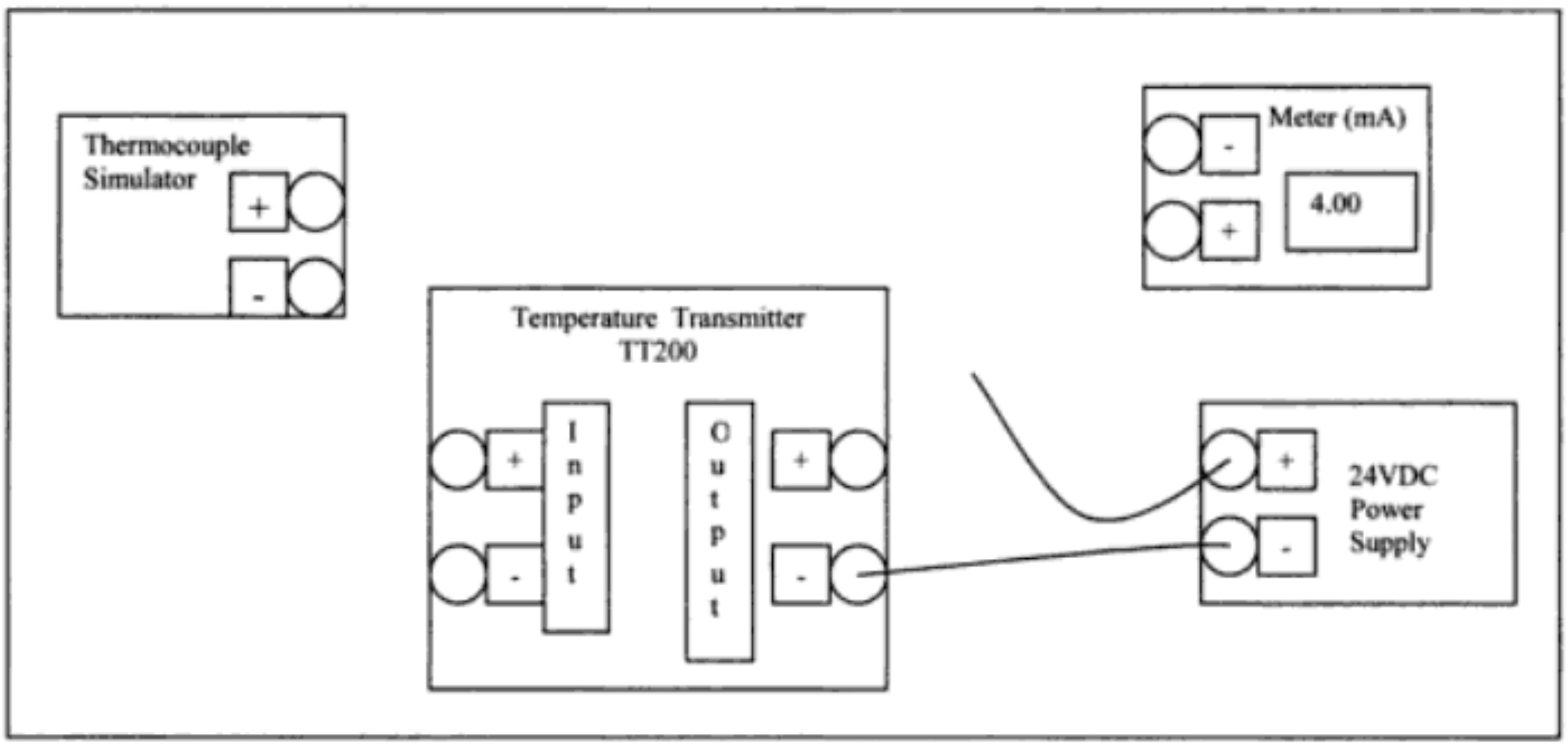
11. What are the correct reference temperatures and corresponding millivolt values to input for a calibration check at the following test points?

% INPUT	TEMPERATURE	MILLIVOLTS
0%		
25%		
50%		
75%		
100%		

12. What are the expected transmitter outputs for the following simulated inputs?

% INPUT	OUTPUT (mA)
0%	
25%	
50%	
75%	
100%	

13. Indicate the correct test equipment hookup for calibration of TT-200.



14. Assume a calibration tolerance of ± 1.0°F/0.08 mA. With the results indicated, what must be done to bring the instrument to within tolerance?

% INPUT	OUTPUT (mA)
0%	4.00
25%	7.98
50%	11.96
75%	15.94
100%	19.92

15. Following adjustment, all "as-left" data is within tolerance. What steps remain to complete the bench calibration?

Situation for questions 16 – 20: The operator suspects that TI-302 is not reading the correct temperature of Reactor 300. You will be performing a calibration of TI-302. Use the references in Appendix A to answer the following questions.

16. What test equipment will be used for calibration of TI-302?

17. What must be performed to safely remove TI-302 from the process?

18. What important consideration must be taken into account for a proper calibration using a temperature block?

19. The thermometer has one external adjustment. With the results indicated, what must be done to bring the instrument to within tolerance?

% INPUT	THERMOMETER INDICATION (°F)
0%	2
25%	34
50%	66
75%	99
100%	>130

20. What would you do if the thermometer was out of tolerance and the thermometer does not have an adjustment available?

For questions 21 – 23 you will be performing a bench calibration of a temperature switch, TSH-205.

21. What is the specified trip point and reset point of TS-205?

Trip _______ Reset _______

22. What type of sensor does TS-205 use?

23. When performing an initial calibration on the bench, is it important to know what function TS-205 will perform once installed? Why or why not?

4

PRESSURE INSTRUMENT CALIBRATION

After completing this chapter, you should be able to:

Calibrate the following pressure instrument types (to ISA standards, where applicable) and determine acceptability:

- *Gauges*
- *Transmitters*
- *Switches*

Select proper calibration procedure and calibration data sheet.

Select appropriate certified test equipment.

Properly set up/connect test equipment to DUT for calibration.

Properly isolate pressure devices and/or remove from service for field calibration.

Return equipment to service following calibration.

Complete and properly maintain calibration documentation.

4.1 WHAT IS PRESSURE?

Air pressure is the force exerted on you by the weight of tiny particles of air (air molecules). Although air molecules are invisible, they still have weight and take up space. Atmospheric pressure is approximately 14.7 pounds per square inch (psi) at sea level. This means that if we could put one square inch of air from the ground to the upper atmosphere on a scale, it would weigh 14.7 pounds. We do not feel this pressure because it also acts internally and is thus balanced. Since there's a lot of "empty" space between air molecules, air can be compressed to fit in a smaller volume. When it's compressed, air is said to be "under high pressure."

There are two ways to look at pressure: (1) the small-scale action of individual air molecules, or (2) the large-scale action of a large number of molecules. Starting with the small-scale action, a gas is composed of a large number of molecules that are very small relative to the distance between molecules. The molecules are in constant, random motion and frequently collide with each other and with the walls of any container. The molecules possess the physical properties of mass, momentum, and energy. As the gas molecules collide with the walls of a container, the molecules impart momentum to the walls, producing a force perpendicular to the wall. The sum of the forces of all the molecules striking the wall divided by the area of the wall is defined to be the pressure. The pressure of a gas is then a measure of the linear momentum of the molecules of a gas.

4.2 CHALLENGES WHEN CALIBRATING PRESSURE

The first thing we have to deal with when calibrating a pressure instrument is the *unit of measure* we're dealing with. There seems to be dozens of units. In the U.S. we usually deal with pounds per square inch (psi), but even with that we need to know if it's absolute or gauge pressure (psia or psig). And although we usually deal with psig, we'll routinely deal with inches of water (H_2O or "w.c.") for low pressure applications. Other units of measure we will be exposed to are: bars (1 bar = 1 atmosphere), inches of mercury (Hg), millimeters of mercury (mm of Hg), millimeters of water (mm of H_2O), microns, torr, pascals (Pa), and dynes/cm^2. Some conversion factors for pressure units are included in Appendix A-7.

Many of the modern pressure calibrators allow us to select the desired units of measure, but we still need to understand the relative pressure we're dealing with to ensure the correct test equipment, pressure module, and tubing/fittings rated for the maximum test pressure are used.

When I first started calibrating, I had a pressure gauge that read about 15 psi high at all test points. I went through a tremendous amount of effort to drain the glycerin from the gauge, remove the cover, and attempt to adjust the gauge needle. When I couldn't get the gauge to calibrate properly, I took it to my supervisor to order a new replacement gauge. My supervisor informed me that the gauge read in psia, my "as-found" data was acceptable, and I ruined a perfectly good gauge. The gauge was ruined because the vacuum that had existed in the gauge case was eliminated when the gauge was opened. This vacuum was present to

Calibration: A Technician's Guide

Mike Cable

This comprehensive review of calibration provides an excellent foundation for understanding principles and applications of the most frequently performed task of a technician. Topics addressed include terminology, bench vs. field calibration, loop vs. individual instrument calibration, instrument classification systems, documentation, and specific calibration techniques for temperature, pressure, level, flow, final control, and analytical instrumentation. The book is designed as a structured learning tool with questions and answers in each chapter. An extensive appendix containing sample P&IDs, loop diagrams, spec sheets, sample calibration procedures, and conversion and reference tables serves as a very useful reference. If you ever calibrate instruments or supervise someone that does, then you need this book.

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