ROSEMOUNT

The Engineer's Guide to Industrial Temperature Measurement

2013 EDITION

EMERSON
Process Management

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The Engineer's Guide to Industrial Temperature Measurement

PREFACE

This handbook provides a thorough discussion of the considerations for selecting the proper measurement system for a wide variety of applications and conditions. The engineered system selection guidelines are suitable for almost every industrial application.

INTRODUCTION

Temperature is the most widely measured variable in the process industries. Temperature is often a critical factor in industrial processing. If a temperature measurement is not accurate or reliable for any reason, it can have a detrimental effect on such things as process efficiency, energy consumption, and product quality.

Even a small measurement error can be disruptive or very costly in some processes, so it's extremely important to be certain your temperature measurements are accurate and reliable. Pharmaceutical processing is an example where an inaccurate temperature measurement might ruin a batch of product worth hundreds of thousands of dollars. For this reason, each measurement system needs to be evaluated and carefully engineered to satisfy the requirements of the process.

In a Safety Instrumented Function in a SIS, poor performance could be deadly, costly or both and an error of 2% is considered a dangerous non-diagnosed fault. An example might be a process that can go exothermic and possibly explode if temperature is not measured and controlled accurately.

Another example of where an accurate measurement has enormous cost consequences is custody transfer where the amount of material that is bought and sold (referred to as custody transfer) is based on a measurement of the volumetric flow rate of gas. The amount of material contained in a specific volume of gas decreases with rising temperatures and increases with falling temperatures. Therefore, it is extremely important to know the exact temperature of the gas when determining volumetric flow rate. Inaccurate temperature measurements during custody transfer applications result in over- or undercharging of customers. This can directly impact a customer's financial performance. A natural gas custody transfer application is one example of where accurate temperature measurements are required.

Measurements are typically made using a sensor (usually a thermocouple or an RTD) and a signal conditioning circuit (either a transmitter or a channel of an input card to a DCS or PLC) to amplify the sensor's low level (ohm or mV) signal to a more robust 4-20mA current signal.

Combined with a field connection head and thermowell components, the sensor and the signal conditioner are called a temperature system or assembly. Systems are available to meet a variety of measurement accuracy and stability requirements. Some applications need only be within a rather loose ±11 °C (±20 °F) of the actual measurement, some look for trends and accuracy is not as important, while others call for extremely tight measurements of up to ±0.01 °C (±0.025 °F). Long-term measurement stability varies from 5.5 to 11 °C (10 to 20 °F) of span per year for non-critical measurements, to those providing better than 0.044 °C (0.08 °F) of span per year for the most critical applications. In all cases the degree of precision of the measurement is limited by the sensor choice.

This handbook will explore the recommendations, the pitfalls, and the trade-offs for various temperature measurement systems. Guidelines will be presented for selecting the proper sensor and signal conditioner to meet a variety of applications. Design of high reliability systems for use in Safety Instrumented Functions (SIF) within Safety Instrumented Systems (SIS) will also be covered.

Examples of operations where accurate and reliable temperature measurement are important include:

- Pharmaceutical bioreactors and fomenters
- Various chemical reactors
- Distillation columns
- Absorbers
- Crystallizers
- Solid state component manufacturing
- Custody transfer

1 – **How to choose the right sensor technology (RTD or T/C)** *(See 4.2.3.1)*

2 – **What is the recommended insertion length for a thermowell?** *(See 4.2.2.2.5)*

3 – **What is the best way to calculate the accuracy of the entire temperature measurement system?** *(See 3.1.4.2 and .3)*

4 – **How to choose the correct thermowell** *(See 4.1.2)*

5 – **What are the recommended grounding best practices?** *(See 4.2.5.2.4.1)*

6 – **What are the sensor lead wire color standards that should be followed?** *(See 3.2.3 and 3.2.4)*

7 – **How to choose the proper transmitter** *(See 3.1.2)*

8 – **What benefits can be gained by using transmitter diagnostics?** *(See of 5.11.1)*

9 – **Why should long sensor wires be avoided and what are the alternatives?** *(See 4.3.4)*

10 – **What is the benefit of transmitter-sensor matching?** *(See 4.2.7)*

11 – **What are the thermocouple temperature ranges?** *(See 3.2.4.4)*

12 – **What are the recommendations for high accuracy measurements?** *(See 3.1)*

13 – **How to protect the measurement from noise interference** *(See 3.1.2.4.1)*

14 – **What are Best Practices for Calibration?** *(See 5.7.2)*

3

Temperature Measurement Basics

TOPIC PAGE

3.1 Transmitters

3.1.1 Overview

For the purpose of this handbook we will confine our discussion to industry standard Intelligent or Smart transmitters as are manufactured by virtually every leading manufacturer. These are microprocessor-based instruments with enormous capabilities for signal processing as compared to the analog transmitters that were the mainstay for many years. In the days of pure analog devices, functions such as calibration, ranging, zeroing, and damping were set using potentiometers. A screwdriver and multi-meter were the tools used to communicate with the transmitter. The signals drifted and required frequent maintenance and were limited to communicating only one piece of information and could drift and suffer offset from electrical interference. This often created an "on-scale" failure, where the process variable appears to be valid, but is in fact wrong.

These analog transmitters evolved over the years from using discreet components like transistors and diodes into to using "chips" or "chip sets" and finally what we now refer to as microprocessors. While analog models are still available from some manufacturers, they have a declining position in the industrial process market.

WHAT ARE THE RECOMMENDATIONS FOR HIGH ACCURACY MEASUREMENTS?

As discussed in Chapter 3.1, selection of a high end microprocessor based transmitter will afford superior performance and a wide array of optional features that can greatly enhance measurement integrity, performance and accuracy.

Proper selection, calibration and installation of the sensor assembly are additional critical components of measurement system accuracy.

A more precise compensation for RTD inaccuracies is provided by Transmitter-Sensor Matching using the transmitter's factory programmed Callendar-Van Dusen equation. While this matching is typically not required for all process measurements, it is the clear choice for those measurements requiring the best possible accuracy.

Refer to:

4.2.9 – Guidance Review for Ensuring Optimal System Performance and Accuracy

3.1.4.3 – Sensor Related Accuracy Factors

3.2.11 – RTD Accuracy / Interchangeability

3.1.4.3.3 – Transmitter-Sensor Matching

A variety of devices are used to measure temperature. These devices, referred to as sensors, are discussed in detail in the Sensors chapter in this handbook. Smart temperature Transmitters accept signals from all industry standard types of Resistance Temperature Detectors (RTDs) and Thermocouples (T/C). Transmitters also can accept millivolt and resistance signals.

The transmitter converts the measurement input signal to high level robust 4-20 mA output signal. Some models have a digital signal output for connection to a remote device or system.

Transmitters are available in a variety of housing styles that may be mounted into any of a wide selection of enclosures that are available in many different materials of construction. Refer to Figure 3.1.1a They may be mounted integrally with a sensor / thermowell assembly at the process measurement point and transmit either a hard-wired or wireless signal. Alternatively, they can be mounted remotely from the sensor assembly in any of several types of enclosures. They can be configured locally or remotely and can provide local indication. They have an array of standard and optional performance features to provide remarkable functionality. Systems may be provided to meet virtually any agency approval requirement.

Figure 3.1.1a – Transmitter Styles

3.1.2 Transmitter Anatomy

Transmitters accept a variety of measurement signals (RTD and T/C for example), process them, and provide a robust output signal. Not all are designed and perform equally. Each major manufacturer incorporates their own engineering expertise gained from months or even years of research and development. This Intellectual Property (IP) sets the higher quality transmitters apart from the others in their ability to process the measurement signal to provide an accurate and stable output signal. The following sections provide a high level overview of common functions of a high quality transmitter.

Transmitters incorporate three subsystems; the input subsystem converts the sensor measurement signal into a digital signal (called Analog-to-Digital conversion or A/D); the signal conditioning subsystem accepts this digital signal and performs various conditioning and mathematical manipulations to produce a digital representation of the temperature measurement; and the output subsystem that converts this digital signal to a robust analog output signal (D/A). Refer to Figure 3.1.2a The following discussion provides further insight.

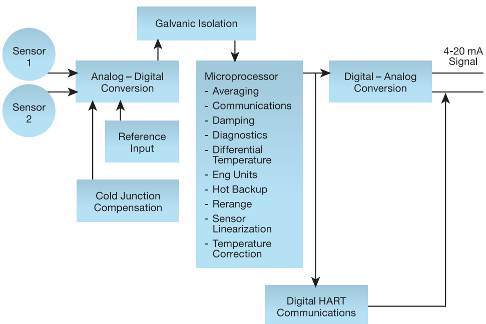


Figure 3.1.2a – Transmitter Functional Block Diagram

3.1.2.1 Inputs

The real world analog signals from measurement sensors are converted to digital signals using a sampling technique with a precisely known internal reference voltage. The more bits of resolution that the A/D uses the more precise will be this conversion.

The most common sensor inputs for temperature measurement are Resistance Temperature Detectors (RTDs) and thermocouples (T/Cs). Additional inputs are millivolt (mV), ohm, and potentiometer. Refer to Figure 3.1.2.1a. A discussion of each type follows.

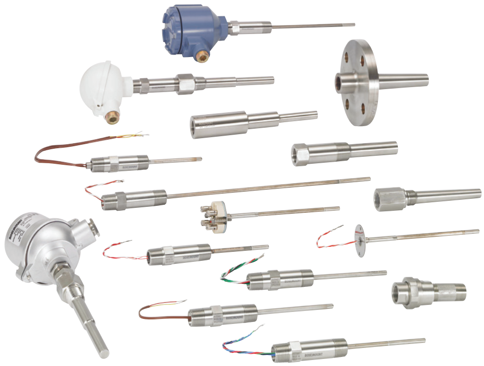


Figure 3.1.2.1a – Typical Sensors

3.1.2.1.1 RTD Inputs

Resistance temperature detectors (RTDs) are based on the principle that the electrical resistance of a metal increases as temperature increases – a phenomenon known as thermal resistivity. Thus, a temperature measurement can be inferred by measuring the resistance of the RTD element.

RTD’s are constructed of a resistive material with leads attached and usually placed into a protective sheath. The resistive material may be platinum, copper or nickel with the most common by far being platinum. Platinum sensors range from 100 Ω (Ohm) to 1000 Ω and are available as two, three, or four wire constructions.

Refer to section 3.2.3 for a detailed discussion of RTDs.

3.1.2.1.2 Thermocouple Inputs

A thermocouple (T/C) is a closed-circuit thermoelectric temperature sensing device consisting of two wires of dissimilar metals joined at both ends. A current is created when the temperature applied to one end or junction differs from the other end. This phenomenon is known as the Seebeck effect, which is the basis for thermocouple temperature measurements.

One end is referred to as the hot junction whereas the other end is referred to as the cold junction. The hot junction measuring element is placed inside a sensor sheath and exposed to the process. The cold junction, or the reference junction, is the termination point outside of the process where the temperature is known and where the voltage is being measured. This cold junction is typically in a transmitter, control system input card or in a signal conditioner.

Transmitters accept inputs from most common industry standard T/C types including types J, K, E, T, R, and S. Many models can also accept the types B and C and Type N, which commonly serves as an alternative to Types R and S.

Refer to section 3.2.4 for a detailed discussion of T/Cs.

3.1.2.1.3 Millivolt Inputs

Millivolt signals are prone to voltage drop losses and noise pickup and need to be converted in the field to robust 4-20 mA current signals for transmission to receiving instrumentation. Millivolt output signals are very common in analysis instrumentation. Additionally most strain-gauge based transducers and load cells are assigned units of measure for weight, force, tension, pressure, torque, and deflection with a full-scale value measured in mV/V of excitation. For example, a load cell with a 10-V excitation supply and a 2-mV/V-gain factor generates an output of 20 mV at full load, whether the load cell was designed to handle 10, 100, or 1,000lbs. Another example of mV output is a Hall-Effect transducer as are typically used in tachometers, contactless switches, magnetizers and compasses and in devices for position, tilt/level, pressure, and thickness measurements.

3.1.2.1.4 Potentiometer Inputs

Potentiometers are basically a variable resistance device where a pickup or "wiper" slides along the resistance in accordance with some external physical movement thus developing a variable resistance output to the transmitter. They are used in a variety of devices to provide position feedback. There are rotary, linear, helical, and string styles. They can be found in speed controls, conveyer controls and in some processing and laboratory equipment.

3.1.2.1.5 Resistance Inputs

Pure Resistance change signals are found in some strain gauges and other bridge circuits.

3.1.2.2 Isolation

An installed measurement loop will very often have two ground level potentials. One is at the point of measurement where the sensor is in contact with the process which in turn is connected to the local ground. The other ground is usually the signal ground which is most often at the receiving instrument in the control room. These grounds will rarely, if ever, be at the same potential. If there is a galvanic path between the two grounds a current will flow dependant on the difference between the two ground voltage potentials. This is referred to as a ground loop and will have a varying and unknown effect on the output signal causing potentially significant error. Most transmitter designs incorporate a means of galvanic isolation using either optic or transformer isolation stages to eliminate this problem.

An isolated transmitter also has provision to block both normal mode and common mode voltages that may inadvertently come in contact with the measurement circuit. Faults in field equipment can inject ac voltages of 120 V, 240 V or even higher into the process equipment and grounded thermocouples, shorted RTDs and cable shields can carry this voltage to the transmitter. High voltage can also be induced by welders, motor starters, lightning strikes and other switchgear. The isolation provided in the transmitter front end will block these voltages preventing them from travelling to the control room ground system causing potentially lethal conditions.

With this isolation being applied a safe digital signal is presented to the signal conditioning stage.

3.1.2.3 Single, Dual and Multipoint Transmitters

All transmitters allow for at least one sensor input. However, some temperature transmitters have a dual-input capability, allowing them to accept inputs from two sensors simultaneously. Dual sensors provide a more reliable measurement through sensor redundancy and by detecting sensor drift and they can also provide a measurement of differential or average temperature of the two sensors. See Figure 3.1.2.3a

Figure 3.1.2.3a – Transmitter with Single or Dual Inputs

Multi-input temperature transmitters accept up to 8 sensor inputs and are useful in applications where many temperature measurement points are concentrated in one area, known as high density transmitters. See Figure 3.1.2.3b.

Figure 3.1.2.3b – Multichannel Transmitter

High density transmitters minimize installation costs in applications such as heat exchangers, boilers, chemical reactors, and distillation columns. They are also often used for temperature profiling of furnaces and reactors. See Figure 3.1.2.3c.

For more information on multipoint sensors refer to section 3.2.6

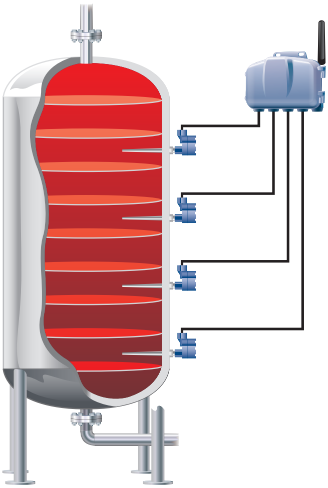


Figure 3.1.2.3c – Temperature Profiling a Reactor

3.1.2.4 Signal Conversion and Conditioning

In this stage the digitized raw temperature measurement signal is filtered, linearized and otherwise mathematically manipulated to yield an accurate representation of the measured temperature.

These processes will be discussed in detail in the following sections.

3.1.2.4.1 Noise filtering

Virtually every plant environment contains electrical interference sources like pumps, motors, Variable Frequency Drives (VFD's) and radios as

HOW TO CHOOSE THE PROPER TRANSMITTER

Transmitters accept a variety of measurement signals (RTD and T/C for example), process them, and provide a robust output signal. Not all are designed and perform equally. Each major manufacturer incorporates their own engineering expertise gained from months or even years of research and development. This Intellectual Property (IP) sets the higher quality transmitters apart from the others in their ability to process the measurement signal to provide an accurate and stable output signal.

A smart transmitter generally provides a more accurate and robust temperature measurement than is provided by direct wired I/O systems. A smart transmitter provides signal isolation, filtering, linearization and sensor type or sensor specific compensation to the measurement before sending the value to the host system.

Transmitters are available in a variety of housing styles that may be mounted into any of a wide selection of enclosures that are available in many different materials of construction. They may be mounted integrally with a sensor/thermowell assembly at the process measurement point and transmit either a hard-wired or wireless signal. Alternatively, they can be mounted remotely from the sensor assembly in any of several types of enclosures. They can be configured locally or remotely and can provide local indication. They have an array of standard and optional performance features to provide remarkable functionality. Systems may be provided to meet virtually any agency approval requirement.

Refer to:

3.1.2.3 – Single, Dual and Multipoint Transmitters

3.1.3 – Output Options

3.1.4 – Transmitter Performance

3.1.5 – Stability

3.1.6 – Intelligent Filtering Features and Options

3.1.8 – Diagnostics

3.1.10 – Transmitter Styles; Housings and Mounting Options

3.1.11 – Transmitter Options

3.1.12 – Safety Certified Transmitters for SIS Applications

4.3.4 – Advantages of Using Transmitters vs. Direct Wiring

well as sources of electrostatic discharge and other electrical transients. A transmitter is designed to reject common mode and normal mode interference as well as provide a high degree of immunity to Electromagnetic Interference (EMI), Electrostatic Discharge (ESD), and Radio Frequency Interference (RFI).

3.1.2.4.2 Linearization:

All T/C's and RTD's have a nonlinear output vs. temperature relationship. If this relationship was ignored, significant errors would result, especially for wider ranges. The transmitter applies a linearization technique that greatly reduces the errors caused by the nonlinearities of sensors thus providing a much more accurate measurement.

The relationship between the resistance change of an RTD vs. temperature is called its Temperature Coefficient of Resistance (TCR) and is often referred to as the RTD's alpha curve. (Refer to section 3.2.3 for more detail.) The transmitter is configured to provide a linear output to compensate for the difference between the alpha curve of a sensor and an ideal straight-line relationship. How closely a sensor's alpha curve matches this ideal straight-line relationship is referred to as its class. For example a Class A sensor has a closer tolerance than does a Class B sensor and will provide a more accurate measurement. See also sensor matching below and in the Engineering Your Temperature Measurement chapter section 4.2.5.2.2.1 and see Figure 3.1.2.4.2a

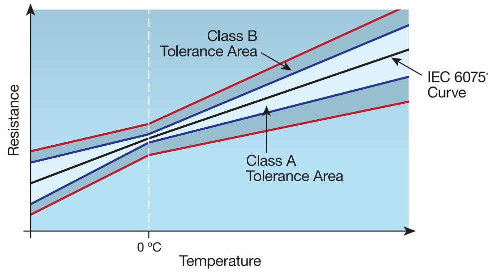


Figure 3.1.2.4.2a – IEC 751 Ideal vs. Class A vs. Class B Tolerance Graph

For each type of T/C there is a corresponding curve of the relationship between the emf generated by the T/C hot junction and temperature. The transmitter is configured to linearize this relationship. See Figure 3.1.2.4.2b.

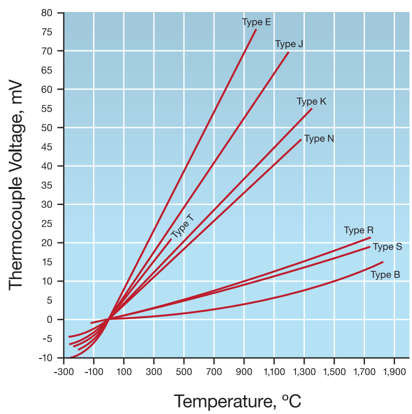


Figure 3.1.2.4.2b – T/C emf vs. Temperature Curves for Popular T/C Types

3.1.2.4.3 Cold Junction Compensation (CJC)

The voltage measured at the cold junction correlates to the temperature difference between the hot and cold junctions; therefore, the temperature at the cold junction must be known for the hot junction

HOW TO PROTECT THE MEASUREMENT FROM NOISE INTERFERENCE

Virtually every plant environment contains electrical interference sources like pumps, motors, Variable Frequency Drives (VFD's) and radios as well as sources of electrostatic discharge and other electrical transients. Low level sensor signals from RTDs and T/Cs are very susceptible to Electromagnetic Interference (EMI), Electrostatic Discharge (ESD), and Radio Frequency Interference (RFI).

Sensor leads act like an antenna for noise interference causing potentially very large errors in the measurement. The longer the leads (The antenna) the greater will be the noise pickup. A transmitter is designed to reject common mode and normal mode interference as well as provide a high degree of immunity to EMI, ESD and RFI. Where possible and practical, transmitters should be mounted close to the measurement point to minimize potential noise pickup by the sensor leads. This is especially important for low level T/C signals which are especially susceptible to noise.

3.1.2.4.1 – Noise filtering

4.3.4 – Advantages of Using Transmitters vs. Direct Wiring temperature to be calculated. This process is known as "cold junction compensation" (CJC). CJC is performed by the temperature transmitter, T/C input cards for a control system, alarm trips, or other signal conditioner. Ideally the CJC measurement is performed as close to the measurement point as possible because long T/C wires are susceptible to electrical noise and signal degradation.

Performing an accurate CJC is crucial to the accuracy of the temperature measurement. The accuracy of the CJC is dependent on two things; the accuracy of the reference temperature measurement and the proximity of the reference measurement to the cold junction. Many transmitters use an isothermal terminal block (often made of copper) with an imbedded precision thermistor, an RTD or an integrated circuit transistor to measure the temperature of the block. Refer to Figure 3.1.2.4.3a

TIP: Refer to section 4.3.4.0 in the "Connecting to the Control System" chapter for a detailed discussion of why it is preferable to use field transmitters vs. direct wiring the sensors over long distances to a control room.

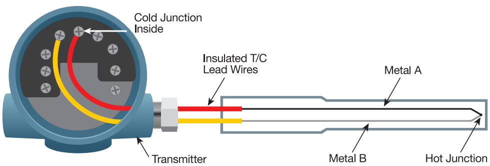


Figure 3.1.2.4.3a – Cold Junction Compensation

Summary of Transmitter Anatomy

A smart or microprocessor-based transmitter performs a succession of operations upon the measurement signal to condition it to provide an accurate and stable digital signal to the output stage. The operations that are performed are quite sophisticated and are often proprietary to the specific manufacturer.

3.1.3 Output Options

After the signal conditioning functions as described above are completed, the isolated, filtered, linearized and compensated digital signal reaches the final transmitter stage of conversion to a robust analog signal for transmission over potentially very long distances to the control room. This analog-to-digital conversion provides a highly accurate signal with excellent noise immunity as compared to the weaker and noise susceptible signals coming directly from the sensor. Further insight is provided in section 4.4.3 in the Connecting to the System chapter.

For many years an analog output signal had been the industry standard approach for communicating signals to a control system, individual controllers or recorders. As digital circuit technology matured, industry began to adopt the concept of using digital communication from field devices in addition to the analog signal or as an alternative to the analog signal.

In the 1980s the HART® protocol was introduced that enhanced the analog signal functionality by providing access to more field device data and the ability to manipulate certain parameters. It also offered a rudimentary digital networking capability.

In the late 1980s and into the1990s several different digital fieldbus technologies were launched globally with the intent of distributing the control architecture to the bus and the field devices.

In the new millennium, wireless technology has evolved to serve as a viable protocol for transmitters. It complements the existing HART protocol by providing access to more data in those hard-to-reach locations.

3.1.3.1 Analog Current

Industry standard 4-20 mA analog signals are used globally to communicate with field mounted devices over long distances. These robust signals are highly resistant to electrical interference. Typically 4 mA represents 0% of the measured value and 20 mA represents 100%. Signals outside of this range indicate a system abnormality or failure condition. Current from the 0 mA to 4 mA portion of the signal range is used to provide operating power to the loop device. This is commonly referred to as a loop-powered device. In a current loop the signal is not affected by the voltage drop of long cable runs or junction boxes.

HART® COMMUNICATION PROTOCOL

3.1.3.2 HART®

The HART (Highway Addressable Remote Transducer) protocol is a digital protocol that provides for the superimposing of a digital signal onto the 4-20 mA signal wires. This superimposed digital signal allows two way communications for configuration and for extracting operational and alarm data from

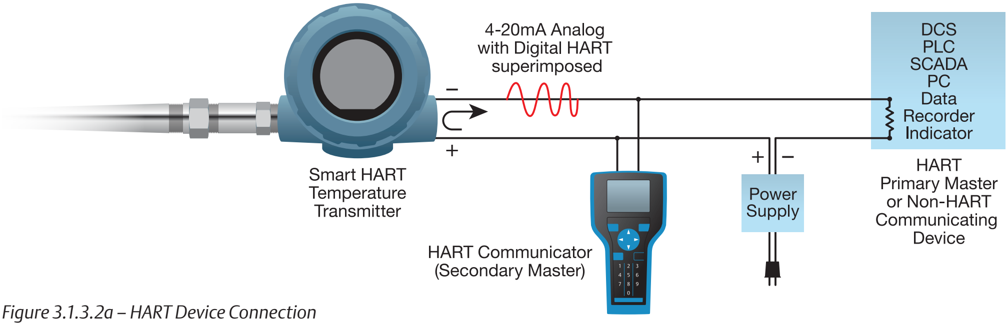


Figure 3.1.3.2a – HART Device Connection

the transmitter. Refer to Figure 3.1.3.2a. HART protocol is widely accepted and utilized throughout the world. Using HART along with the 4-20 mA signal offers enhanced diagnostics options including status and alarm data that can be useful for maintenance or process analysis.

On a very basic level, field configuration tools can access any of this information by request one instrument at a time. An alternative solution to accessing this information exists on a higher level where this data can be accessed continuously from all field devices simultaneously using fieldbus or HART-enabled multiplexors interfaced with the DCS and/or an asset management system.

3.1.3.3 FOUNDATION™ Fieldbus

Foundation Fieldbus is an all-digital, serial, two-way communications system that can serve as the base-level network in a plant or factory automation environment. It is an open architecture, developed and administered by the Fieldbus Foundation.

It’s targeted for applications using basic and advanced regulatory control, and for much of discrete control associated with those functions. Foundation fieldbus technology has been widely used globally in the process industries.

Fieldbus installations may use any or a combinations of field topologies where measurement and cointrol devices are distributed throughout the plant to best meet the needs of the application. These topologies connect to an I/O rack and then to the plant control highway using a network of high speed ethernet cables, junction boxes, device couplers and power supplies. Refer to vendor documentation for additional detail.

3.1.3.4 PROFIBUS

PROFIBUS is an international fieldbus communications standard for linking process control and plant automation modules. Instead of running individual cables from a main controller to each sensor and actuator, a single multi-drop cable is used to connect all devices, with high speed, bi-directional, serial messaging used for transfers of information. Profibus DP is used for discrete signals and has had extensive use in factory automation applications. Profibus PA is used for analog process control signals and has gained widespread use in the process control industry. Both protocols may be connected together using a coupling device. Similar to foundation fieldbus, Profibus networks use a distributed system of measurement and control devices connected to a plant control highway. Refer to vendor documentation for additional detail.

3.1.3.5 WirelessHART™

WirelessHART™ is an open-standard wireless networking technology developed to complement the existing HART standard. The protocol was defined specifically for the requirements of process field device networks and utilizes a time synchronized, self-organizing, and self-healing mesh architecture. Refer to Figure 3.1.3.5a. The protocol currently operates in the 2.4 GHz ISM Band using IEEE 802.15.4 standard radios. It is backward compatible with existing HART systems and configuration tools allowing for easy adoption with minimal training. As with the HART devices described above the information embedded in the HART signal may be accessed by field devices or HART-enabled I/O systems and processed by the DCS and/or an asset management system.

Figure 3.1.3.5a – Wireless HART Network

It is especially useful in remote and hard-to-reach locations throughout a plant (remote storage tanks or pipelines, for example) where installing wiring over long distances, under/over roadways and railroad tracks etc. would be very expensive. See Figure 3.1.3.5b.

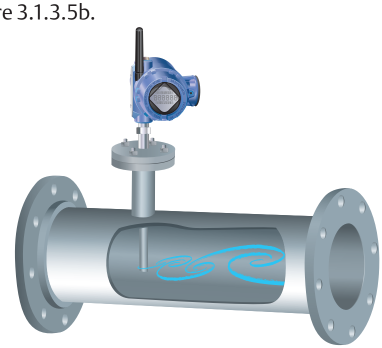


Figure 3.1.3.5b – Wireless Remote Mount Pipeline Installation

Output Options Summary

In summary, transmitters have three primary stages. The input stage provides the A/D conversion of the analog sensor signal to a digital signal that is passed to the second stage for signal conditioning and mathematical manipulation. The third stage converts the digitally processed signal back into an analog signal in the D/A converter for output to the receiving device. High quality transmitters incorporate years of expertise into their designs. This Intellectual Property is what sets them apart from lesser quality products.

3.1.4 Transmitter Performance

3.1.4.1 Temperature Measurement Performance Factors

Temperature measurement system performance is influenced by a number of factors in reporting process temperature measurements, including accuracy, stability, internal conditions, intelligent filtering, response time and diagnostics.

3.1.4.1.1 Accuracy

Accuracy of a temperature measurement system is the degree of closeness of the measurement of a temperature to that temperature's actual (true) value.

3.1.4.1.2 Repeatability

The repeatability of a measurement system, also called precision, is the degree to which repeated measurements under unchanged conditions show the same results.

As an example, an instrument could present the same value for temperature every time (under the same measurement conditions) but the value is offset from the correct value. This is repeatable but not accurate. The ideal measurement therefore would be both accurate and repeatable.

For those familiar with target shooting, a marksman could tightly cluster his shots on the target (repeatable) but the cluster may not be in the bull's-eye. (Accuracy) The ideal situation is to have all the shots closely clustered in the bull's-eye. (This result is both accurate and repeatable). See Figure 3.1.4.1.2a

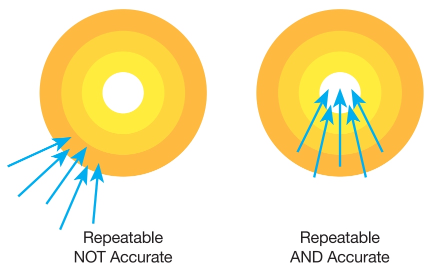


Figure 3.1.4.1.2a – Accuracy vs. Repeatability

WHAT IS THE BEST WAY TO CALCULATE THE ACCURACY OF THE ENTIRE TEMPERATURE MEASUREMENT SYSTEM?

Refer to:

3.1.4.2 – Error Calculations

Worst Case Error (WCE) is the largest possible error expected under the anticipated conditions. These calculations are a summation of the raw values of reference accuracy, digital temperature effect, and ambient temperature effects on the input and output.

Total Probable Error (TPE) is a calculation that reflects the probable error of the transmitter and sensor system, based on anticipated installation conditions. The components of this calculation include the root sum square of the multiple transmitter and sensor accuracy effects.

See also:

3.1.4.2. 1 – Example Error Calculations

3.1.4.3 – Sensor Related Accuracy Factors

3.1.4.3.3 – Transmitter-Sensor Matching

4.2.7 – System Error Analysis

3.1.4.1.3 Input Accuracy

The input accuracy (also called digital accuracy) is unique for each sensor input. For example, the input accuracy of an RTD is about +/- 0.1 °C (0.18 °F) for a high quality transmitter. The input accuracy of a T/C varies by T/C type from about +/-0.2 °C (0.36 °F) up to +/-0.8 °C (1.44 °F).

There are many factors that affect the accuracy of a transmitter, including ambient temperature compensation, CJC and sensor selection.

3.1.4.1.4 Output Accuracy

This is a statement of the accuracy of the D/A converter stage given as a % of span. (Typical is 0.02% of span.)

3.1.4.1.5 Ambient Temperature Compensation

Both input and output accuracy will vary with fluctuations in the ambient temperature of the transmitter. This is referred to as the ambient temperature effect. Typical errors for a 100Ω platinum RTD (α =0.000385) for each °C change in ambient temperature are 0.0015 °C (0.0027 °F) for the input and 0.001% of span for the output. These errors are as compared to a reference ambient temperature (specified by the manufacturer) of 20 °C (68 °F). T/Cs have similar data.

Transmitters are characterized during manufacturing over their specified operating range to compensate for these fluctuations to maintain measurement accuracy and stability. Typical transmitter ambient temperature range is -40 to 85 °C (-40 to 185 °F).

3.1.4.2 Error Calculations

Worst Case Error (WCE) is the largest possible error expected under the anticipated conditions. These calculations are a summation of the raw values of reference accuracy, digital temperature effect, and ambient temperature effects on the input and output.

Total Probable Error (TPE) is a root sum of the squares of multiple error producing factors affecting the accuracy. It is based on anticipated installation conditions.

3.1.4.2.1 Example Error Calculations

For a 4-20mA HART transmitter when using a Pt 100 (α =0.000385) sensor input with a 0-100 °C span operating at an ambient temperature of 30 °C (86 °F), the following statements would be true: (Using the typical error data listed above in 3.1.4.1.4 and 3.1.4.1.5 and as found in a product data sheet)

3.1.4.2.1.1 Digital Temperature Ambient Change Effects (Input Error)

Input Error = (Ambient temperature effect) x (Change in ambient)
= (0.0015 °C/ °C) x (30°- 20°)
= 0.015 °C (0.027 °F)

3.1.4.2.1.2 D/A Ambient Change Effects (Output Error)

D/A Effects = (Transmitter D/A Spec from data sheet) x (Temp span) x (Change in Ambient Temp)
= 0.001%/ °C x Temp Span x (Amb Temp – Cal Temp) °C
= 0.001%/ °C x 100 °C x (30-20) °C
= 0.001%/ °C x 100 °C x 10 °C
= 0.01 °C (0.018 °F)

3.1.4.2.1.3 Worst Case Error (WCE)

WCE = Digital (Input) Accuracy + D/A (Output) Accuracy + Ambient Change Digital Temp Effects + Ambient Change D/A Effects
= Input error + Output error + Ambient change effect on input + Ambient change effect on output
$= 0.1\,°C + (0.02\,\%span/\,°C)\,(100\,°C) + 0.015 + 0.01$
$= 0.1\,°C + 0.02\,°C + 0.015\,°C + 0.01\,°C$
$= 0.145\,°C\ (0.261\,°F)$

3.1.4.2.1.4 Total Probable Error (TPE)

(For 100 °C span and using specifications from a typical product data sheet)

TPE $= \sqrt{(\text{Transmitter specified digital input accuracy})^2 + (\text{Output (D/A) error spec})^2 + (\text{Ambient change effect on Input})^2 + (\text{Ambient change effect on output})^2}$
$= \sqrt{(\text{Digital})^2 + (\text{D/A})^2 + (\text{Dig Temp Effects})^2 + (\text{D/A Effects})^2}\ °C$
$= \sqrt{(0.1)^2 + (0.02)^2 + (0.015)^2 + (0.01)^2}\ °C$
$= 0.1\,°C\ (0.18\,°F)$

3.1.4.3 Sensor Related Accuracy Factors

3.1.4.3.1 – Cold junction compensation (CJC) is crucial to the accuracy of the temperature measurement when a thermocouple is used. Since the accuracy of the CJC depends primarily on the accuracy of the reference temperature measurement, a precision thermistor or platinum RTD is commonly used to determine this temperature.

3.1.4.3.2 – Proper selection, calibration and installation of the sensor assembly is another critical component of measurement system accuracy. All sensors have inherent inaccuracies or offsets from an ideal theoretical performance curve referred to as sensor interchangeability. Transmitters can compensate for this offset by allowing the user to make adjustments to the factory defined sensor curves stored in the transmitter memory by digitally altering the transmitters interpretation of the sensor input. Factory calibrations can also be performed using either three or five-point data. Refer to the Calibration Chapter for more information.

3.1.4.3.3 Transmitter-Sensor Matching

A more precise compensation for RTD inaccuracies is provided by Transmitter-Sensor Matching using the transmitter's factory programmed Callendar-Van Dusen (CVD) equation. This equation describes the relationship between resistance and temperature of platinum resistance thermometers (RTDs). The matching process allows the user to enter the four sensor specific Callendar-Van Dusen (CVD) constants into the transmitter. The transmitter uses these sensor-specific constants in solving the CVD equation to match the transmitter to that specific sensor thus providing outstanding accuracy. Accuracy improvement for sensor matching is typically 7:1. Refer to Figure 3.1.4.3.3a and the Sensor chapter for a more complete discussion.

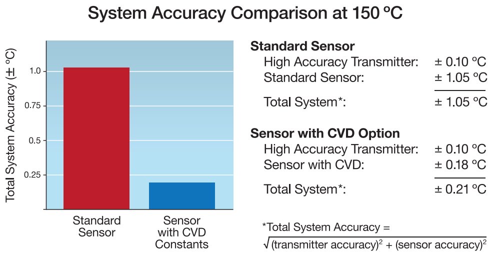


Figure 3.1.4.3.3a – Sensor - Transmitter Matching Comparison

3.1.5 Stability

Stability refers to the ability of the transmitter to avoid drift in order to maintain accuracy over time. It is related to the sensor's measurement signal, which can be influenced by humidity and prolonged exposure to elevated temperatures. Stability is maintained by using reference elements in the transmitter, against which the sensor input is compared. At superior transmitter manufacturers, in order to improve accuracy and stability, every transmitter is fully temperature characterized to compensate for the temperature-dependency of the D/A and A/D in order to improve accuracy and stability.

Stability is often stated in terms of percent of the reading or the expected maximum change in measured temperature in °C or °F over a specified amount of time for each sensor type. Data is typically given for 1 year, 2 years or 5 years. For example: 0.25% of reading or 0.25 °C (0.45 °F) for 5 years (Whichever is greater) is typical for RTDs and 0.5% of reading or 0.5 °C (0.9 °F) for 5 years (Whichever is greater) for T/Cs. Transmitter calibration cycles for high quality smart transmitters can be extended accordingly. Figure 3.1.5a

Tip: The stability specification above refers to the transmitter performance and does not include the sensor itself. A well made RTD is generally considered to be highly stable and will not degrade significantly over time. However, even a well made T/C will degrade measurably over time and much more quickly at high temperatures. Refer to section 3.2.3 for more information.

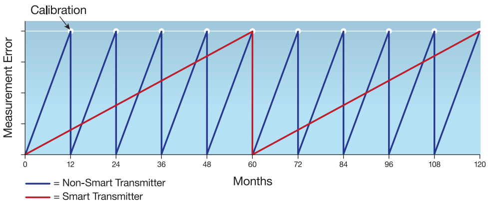


Figure 3.1.5a – Comparing Smart vs. Non-Smart Transmitter Stability

3.1.6 Intelligent Filtering Features and Options

In most plant environments surges from lightning or other static discharge are common as are electrical power surges and dips. There can be other hostile conditions caused by vibration, high humidity, high or low ambient temperature, and corrosive atmosphere etc. that can adversely affect transmitter performance as well. Fortunately, many manufacturers have design features and configuration options that address these issues and help to provide a reliable temperature measurement. Many of these are discussed below.

3.1.6.1 Damping

Damping is the amount of time required, in addition to the update time, for the output to reach 63.2% of its final value after a step change has been applied to the input. See Figure 3.1.6.1a. It is adjustable from 1 to 32 seconds. Damping reduces the effects of electrical noise and any other insignificant transient noise that may influence the transmitter output signal. It is often used to stabilize control loops and prevent false trips. In the absence of electrical or transient noise, damping may not be required since temperature changes in most processes are slow and have inherent lag time in influencing the sensor due to thermowell inertia etc. Additionally, for fast changing process conditions or to identify runaway conditions as early as possible, damping should be minimized.

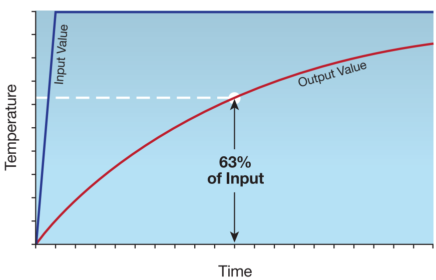


Figure 3.1.6.1a – Damping Response Curve

3.1.6.2 Open Sensor Holdoff

The Open Sensor Holdoff option detects a false open sensor condition and performs calculations to determine when the transmitter should send an indication to the control system. For example, the transmitter determines if an open sensor event has actually occurred or a high voltage transient event, such as lightning or electrostatic discharge, has caused a false open sensor condition. To avoid an unnecessary alarm and possible process control disruption, the established temperature value continues to be sent until the transmitter identifies the true source of the condition and takes the appropriate failure action only upon a verified sensor failure. See Figure 3.1.6.2a

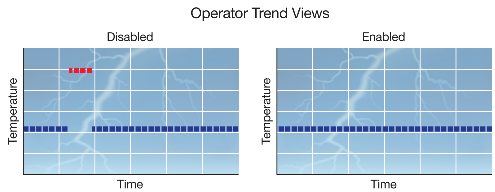


Figure 3.1.6.2a – Open Sensor Holdoff

3.1.6.3 Transient Filter

The Transient Filter feature recognizes conditions like high vibration or a noisy environment that may cause incorrect intermittent temperature readings and rejects them. By disregarding these temperature spikes, sensor signal interruption is prevented and the last known reliable temperature continues to be transmitted thus saving a potential process upset or trip condition. See Figure 3.1.6.3a

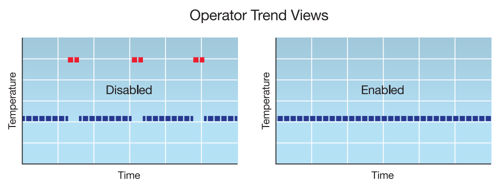


Figure 3.1.6.3a – Transient Filter

3.1.6.4 EMF Compensation

In temperature measurement loops using RTDs, small voltages, called thermal EMFs, can be induced on the sensor wires, increasing the effective resistance and causing false temperature readings. Rosemount transmitters feature Emerson's patented EMF Compensation, which monitors RTD sensor loops and compensates for the unwanted thermal EMF voltages. As a result, these transmitters deliver more accurate and reliable temperature values.

3.1.6.5 Line Voltage Filter

Noise from nearby 50 or 60Hz AC voltage sources, such as pumps, variable frequency drives, or power lines is easily detected by low-amplitude sensor signals. If not recognized and removed, this noise can compromise the transmitter's output signal. A transmitter's Line Voltage Filter can be customized at 50 or 60 Hz to protect temperature measurements from AC voltage interference and to filter out this noise, enabling the delivery of accurate temperature readings. Verify the voltage to be used in the country of installation. See Figure 3.1.6.5a.

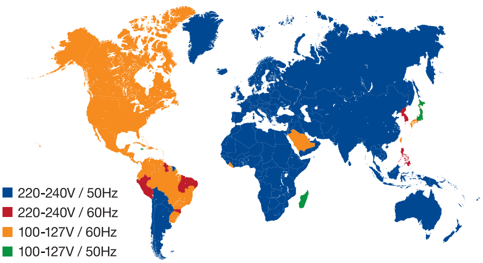


Figure 3.1.6.5a – Global Voltage Usage

3.1.6.6 The Hot Backup® Feature

The Hot Backup® Feature is the ability of the transmitter to automatically switch the transmitter input from the primary sensor to the secondary sensor should the primary sensor fail. This prevents a process disruption due to the failure of the primary sensor. A maintenance alert is also generated to notify operators that a sensor has failed and the Hot Backup® feature is active. In this way, a critical temperature measurement is not lost, and control is not disrupted. See Figure 3.1.6.6a.

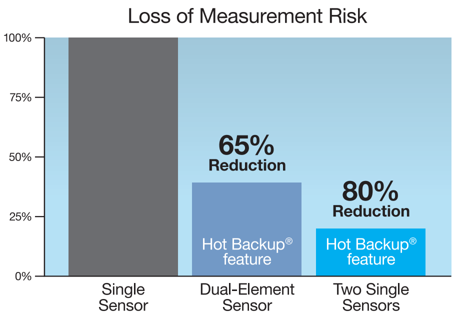


Figure 3.1.6.6a – The Hot Backup® Feature Prevents Primary Sensor Failure from Disrupting Process Control

Tip: See the "Selecting and Installing the Correct Temperature Components" section 4.2 for more on redundant sensor applications using two single sensors.

3.1.6.7 Sensor Drift Alert

Sensor Drift Alert notifies the control system of the degradation of a sensor that is causing its measurement signal to drift away from the actual value, thus decreasing the measurement integrity. By using two sensor inputs, the difference between the two sensors is monitored. When the difference becomes greater than a value entered by the user, the transmitter sends an alert to indicate a sensor drift condition. See Figure 3.1.6.7a

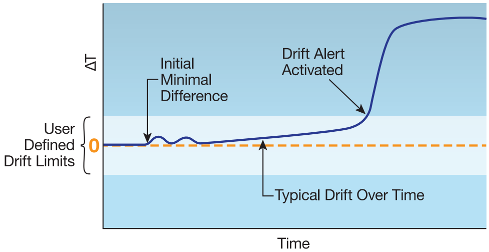


Figure 3.1.6.7a – Sensor Drift Alert Detects a Degrading Sensor

3.1.6.8 Thermocouple Degradation

The Thermocouple Degradation feature continually monitors the resistance of the thermocouple loop. If the resistance goes above a certain designated trigger level, an alert is sent suggesting sensor replacement. The degrading thermocouple can be caused by wire thinning, sensor breakdown, moisture intrusion or corrosion and can be an indication of an eventual sensor failure. Identifying this degraded condition prior to a complete T/C failure could prevent an unscheduled process trip and save an expensive unscheduled shutdown.

3.1.6.9 Minimum-Maximum Tracking

Use Minimum-Maximum Tracking Tracking to verify installation temperature or to troubleshoot quality issues. This feature keeps records of both the process and ambient temperature values. This enables a user to verify that the internal transmitter temperature has not exceeded recommended limits in areas where the ambient temperature around the transmitter fluctuates substantially. Operating a transmitter above its published maximum operating temperature may cause premature failure and/or invalid outputs. Operating it below its rated ambient temperature may lead to degradation of the accuracy. Also, this Minimum-Maximum Tracking feature records the minimum and maximum temperatures reached by the sensors and their differentials, which can be helpful when troubleshooting product quality issues by indicating whether or not optimal temperatures have been maintained.

TIP: This feature could be very useful for documenting the performance of a transmitter used in a Safety Instrumented loop.

3.1.7 EMI Compliance

Transmitters are designed to withstand and reduce the effects of electromagnetic interference (EMI). This includes the use of shielded circuit cards, shielded housings, proper circuit design, and appropriate parts selection. A quality transmitter provides a high level of electromagnetic compatibility (EMC), whereas the more economical transmitters may have reduced EMC levels.

Compliance with national or international standards is often required by laws passed by individual nations. Different nations can require compliance with different standards.

For example; by European law, manufacturers of electronic devices are advised to run EMC tests in order to comply with compulsory CE-labeling.

3.1.8 Diagnostics

Transmitters often have diagnostics. There are internal diagnostics that monitor transmitter memory and output validity. Also, there are external diagnostics that check the sensor.

Transmitters initiate either Alerts or Alarms based on these diagnostic processes.

Alerts cover diagnostics that are determined not to affect the transmitter's ability to output the correct measurement signal and therefore will not interrupt the 4-20 mA output. An example is "Process Variable Out-of-Range". See Figure 3.1.8a.

Alarms cover diagnostics that are determined to affect the transmitter's ability to output a correct value of the measurement. Detected alarms will drive the transmitter output either high or low depending on user's choice.

Alerts and alarms can be read on a local indicator (if so specified), on a field communicator or on a HART-compliant monitoring system like an asset management system.

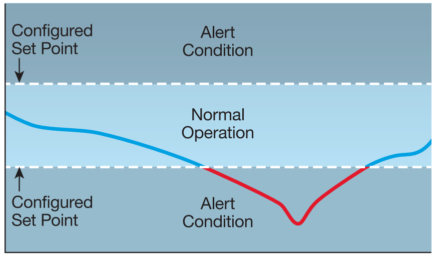


Figure 3.1.8a – Configurable Process Alerts

3.1.8.1 Internal Diagnostics

Internal diagnostics perform internal checks for corrupted memory. Also, diagnostics check for erroneous fixed outputs due to transmitter processing being stuck in infinite loops. Many of the internal diagnostics are proprietary to the transmitter manufacturers.

3.1.8.2 External Diagnostics

External diagnostics monitor measurement validity due to external sources, such as the sensor wiring connections, noise on the sensor, and sensor failure.

3.1.8.3 Open/Short Sensor Diagnostics

Open/Short Sensor Diagnostics identifies an open sensor connection or a short in the sensor connection and generates an alarm. Open sensors can be caused by shock, vibration, corrosion, wire thinning or fraying. Shorted sensors could be the result of vibration, bent wiring, or contamination. Open or short sensors are the most common sensor failure conditions. This diagnostic is helpful in determining why a measurement point failed.

Tip: This option could be very useful for high vibration applications where sensor failure is more common.

3.1.8.4 Measurement Validation Diagnostic

3.1.8.4.1 Deviation Alarming

Before a sensor fails, it will exhibit signs of degradation such as increased signal noise which will often result in inaccurate on-scale readings. Measurement Validation is a diagnostic that can provide validation of temperature measurement data, ensuring visibility of measurement and process abnormalities before a sensor failure occurs. Measurement Validation monitors the signal noise and uses it to calculate a deviation value indicating the magnitude of the noise which is compared to a user selected alert limit. When this limit is exceeded, the user is notified, allowing action to be taken. Measurement Validation can also detect on-scale failures associated with loose or corroded connections, high vibration and electronic interference which can contribute to a signal noise increase.

3.1.8.4.2 Rate-of-Change Alarming

In addition to detecting on-scale failures and validating measurement values, Measurement Validation also performs a rate of change calculation which can be used to identify abnormally fast temperature changes that could indicate a runaway reaction condition even before alarm conditions are met.

3.1.8.5 Diagnostics Log

The Transmitter Diagnostics Logging feature stores advanced diagnostic information between device resets, such as what caused the transmitter to go into alarm, even if that event has disappeared. For example, if the transmitter detects an open sensor from a loose terminal connection, the transmitter will go into alarm. If wire vibration causes that wire to begin making a good connection, the transmitter will come out of alarm. This jumping in and out of alarm is frustrating when trying to determine what is causing the problem.

However, the Diagnostics Logging feature keeps track of what caused the transmitter to go into alarm and saves valuable debugging time. This information is available from the field communicator and/or from an asset management system. See Figure 3.1.8.5a

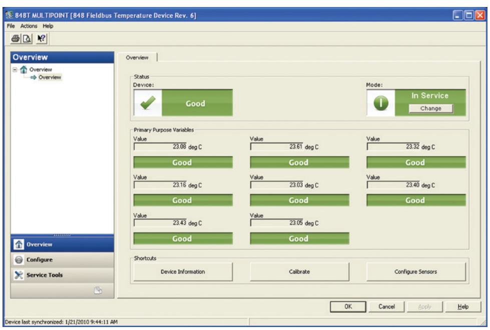


Figure 3.1.8.5a – Typical Diagnostics Log

3.1.9 Response Time Considerations

There are several considerations when analyzing the response time of a temperature measurement system. In most cases the sensor/thermowell response is by far the limiting factor of any system. There are lag times associated with the sensor itself and for the thermowell into which it is inserted that are usually significant. Refer to the Sensor chapter for more detail on sensor response time. The transmitter response to noise and transient filter situations is addressed by the damping adjustment which is adjustable from 1 to 32 seconds and the functionality and adjustment of the transient filter monitoring algorithm. Process temperature changes less than the threshold setting of the algorithm will be reported without delay.

For applications in Safety Instrumented Systems (SIS) the transmitter response is considered to be 5 seconds.

Typical transmitter update time is 0.5 seconds.

Consideration must also be given to the control loop response requirements. For fast changing processes the control algorithm requires more frequent updates than it does for a slow changing process. Transmitter response plus the damping time must be within the allowable window.

3.1.10 Transmitter Styles, Housing and Mounting Options

There are a variety of choices for mounting a transmitter that are driven by process conditions at the point of measurement, plant standards and policies, and user preference. See Figure 3.1.10a

Figure 3.1.10a – Transmitter Family

A methodical approach of reviewing all related factors will very likely present the best choice. Here are some examples of questions that must be answered to drive the selection process.

- Is the ambient temperature expectation at the measurement site within the limits of the transmitter specification?
- Is the measurement site easily accessible?
- Is local temperature indication required? Where can operator see display?
- Is there high vibration at the measurement point?
- What is the area classification? What is the approval agency?
- Does the plant site require Intrinsically Safe (IS) installation?
- Are there sources of EMI, RFI or electrical transients near the measurement point?
- Is this measurement associated with a SIS?
- Is there a sanitary consideration?
- Is there a corrosive environment?

Tip: Many times a site inspection and consultation with process engineering and operations will greatly facilitate the choice.

The most common mounting styles are:

- Head-mount
- Field-mount or Dual compartment
- Rail-mount

3.1.10.1 Head-mount

Head-mount transmitters are compact disc shaped transmitters most often mounted within a connection head which can be field mounted. Most common styles are DIN A and DIN B which differ slightly in dimensions and mounting method. However, the distance between the mounting screws is identical. See Figure 3.1.10.1a.

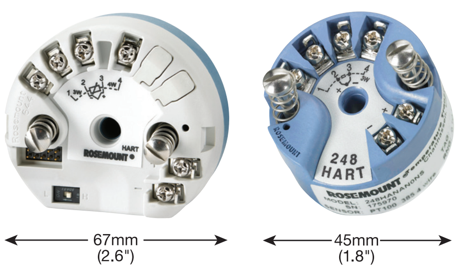


Figure 3.1.10.1a – DIN A and DIN B Head-mount Housing Styles

These are commonly mounted in single compartment housings, such as sensor connection heads or junction boxes. Figure 3.1.10.1b and Figure 3.1.10.1c They can be mounted integrally with the sensor or remotely from the sensor. For integral mounting the transmitter housing is threaded directly onto the sensor / thermowell assembly. With the remote mount, the transmitter is installed within a housing on a pipe stand or other support in the vicinity of the sensor assembly.

Figure 3.1.10.1b – Head-Mount Transmitter Assembly

Figure 3.1.10.1c – Head-Mount Exploded View

It must be noted that single compartment housings may allow moisture or other contaminants egress through improperly sealed conduit connections. Exposure of the terminal strip and the electronics assembly to these contaminants could potentially cause damage to the transmitter.

3.1.10.2 Dual Compartment

Dual-compartment transmitter housings, often known as field mount, are a two part housing that isolates the transmitter electronics module from the terminal strip compartment to protect it from exposure to harsh plant environments. The terminal compartment contains the terminal and test connections for the sensor and signal wires and provides access to the terminal block for wiring and maintenance while isolating the transmitter electronics.

The electronic module with an optional display is in the second compartment. Any moisture / humidity or other contaminants that might find ingress into the housing through the conduit connections will be contained in the terminal section and not come in contact with the electronics thereby greatly reducing the risk of damage from environmental effects. Another benefit is the increased immunity of the electronics from EMI and RFI that may be conducted by the wiring. See Figure 3.1.10.2a

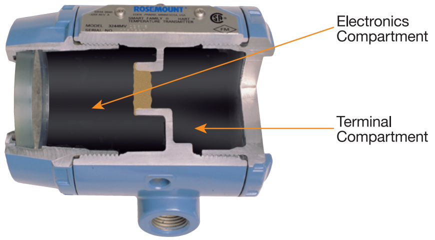


Figure 3.1.10.2a – Dual Compartment Housing

Dual compartment transmitters can be mounted directly on the sensor assembly or remotely on a pipe stand or other support in the vicinity of the sensor. Remote mounting may be necessary when the measurement point is inaccessible or when the process environment prevents the transmitter from being installed integrally with the sensor. See Figure 3.1.10.2b.

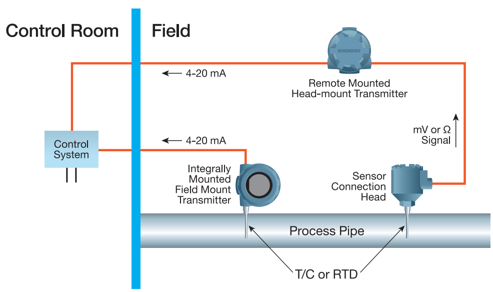


Figure 3.1.10.2b – Dual compartment Transmitters

The transmitter will operate within specifications for ambient temperatures between -40 and 85 °C (-40 and 185 °F). Since heat from the process is transferred from the thermowell to the transmitter housing, if the expected process temperature is near or beyond specification limits, consider using additional thermowell lagging, an extension nipple, or a remote mounting configuration to isolate the transmitter from the process. See Figure 3.2.10.2c.

TIP: While direct mounting of the transmitter will always improve noise immunity because the connection leads are not exposed to the noisy plant environment, the driving factors in selecting the mounting location will usually be ease of access to the point of measurement, environmental issues like high temperature or corrosives at the measurement point, ensuring that the operator can easily view the indicator and / or for ease of access for maintenance.

Figure 3.2.10.2c – Remote Mount Installation

3.1.10.3 Rail-mount

Rail-mount transmitters are thin rectangular transmitters that are typically attached to a DIN-rail (G-rail or top-hat rail) or fastened directly onto a surface. This provides a compact high-density installation where a number of rail-mount transmitters can be placed very closely together on the same DIN-rail. Unlike the field-mount transmitters, the DIN rail style are not designed for harsh environments nor can they be used in areas designated as explosion-proof. See Figure 3.1.10.3a.

Figure 3.1.10.3a – Rail-mount Transmitters

These rail-mount transmitters are usually located in a mild or controlled environment in or near a control room where they are convenient for maintenance and away from harsh process plant conditions. However, when rail-mount transmitters are installed near a control system, the sensor lead wires generally run long distances, making these installations much more susceptible to electromagnetic noise (EMI) and RFI.

Another alternative rail-mounted option is a Multichannel Rail-Mount Transmitter. One or more of these instruments can be mounted into a field enclosure. See Figure 3.1.10.3b.

Figure 3.1.10.3b – Multichannel Rail-Mount Transmitters

Tip: While there may be an advantage to using the Rail-mount transmitters from a transmitter cost point-of-view, the extra expense of long lead wires (4 conductor for RTD's and T/C extension wire for T/C's), potentially degraded performance due to EMI and RFI, and for lead-wire deterioration induced drift of T/C extension wires may easily justify using the much more robust field-mount transmitter models. This is especially valid for high accuracy / high stability measurements and for installations in electrically harsh / noisy environments.

3.1.10.4 Sanitary Housings

Applications in the biotech, food, beverage, and pharmaceutical industries often require sanitary housings and enclosures. These are typically manufactured from stainless steel and are sealed and are suitable for the wash-down and sterilization processes demanded by these industries. The surface finish is typically polished to 32 RMA.

The housings may be either head-mount or remote-mount styles and offer indicating and field configuration options. See Figure 3.1.10.4a.

Figure 3.1.10.4a – Sanitary Housing Transmitter

Housing and Mounting Option Summary

In summary, there are many factors to be considered in the selection of the optimum mounting style and housing. Since any length of connection cable for the sensor input or the output serves an antenna for EMI and RFI, a transmitter directly mounted to the sensor is almost always the better choice. However, as was discussed above, overriding factors of environment and view-ability of indicators etc. may suggest remote-mount options. Some projects lend themselves to high density rail-mount options. For harsh field environments a dual compartment housing is far superior to the single compartment housing in protecting the electronics from exposure to humidity, moisture, or other contaminants. Refer to the Engineering and Design Chapter 4 for additional guidance.

3.1.11 Transmitter Options

There are a variety of additional options and features for a transmitter that may make it easier to use, install, calibrate and maintain. Some of the more popular and recommended options are described below.

3.1.11.1 Dual and Multipoint Options

As discussed in section 3.1.2.3 many transmitters have an option of dual inputs that can be used for redundancy with the Hot Backup® feature switching, drift monitoring, differential temperature measurements or T/C degradation monitoring.

Other models are designed to accept up to 4 or 8 individual sensor inputs, each with their own output signal. These may be used for high density measurements such as profiling applications.

3.1.11.2 Local Display

Many models offer a liquid crystal display (LCD) that attaches to the face of the transmitter. There are two types, standard and local operator interface.

3.1.11.2.1 Standard LCD display

The standard LCD displays show the measured temperature, range, engineering units, device status, error messages and diagnostic messages. See Figure 3.1.11.2.1a.

Figure 3.1.11.2.1a – Dual compartment Transmitter with LCD Display

3.1.11.2.2 Local Operator Interface (LOI) Display

The LOI interface provides the ability for local configuration of the device to make changes in real time without having to attach a laptop or field communicator. The buttons on the LOI are used to perform the configuration tasks by following a menu of configuration information. When the LOI is not being used for configuration, the display will show the same information as the Standard LCD. See Figure 3.1.11.2.2a.

Figure 3.1.11.2.2a – Head-mount Transmitter with LOI

Typical Configuration Menu Selections

- Sensor Type
- 4 mA Value
- 20 mA Value
- Engineering Units
- Damping
- Failure/Saturation Mode
- Line Voltage Filter Frequency

3.1.11.3 Transient Protection

Most high quality transmitters are generally protected by integral galvanic isolation from potential damage from high voltage induced by welders, motor starters, lightning strikes, switchgear and inadvertent exposure to power lines up to 500 to 700 VAC.

However, lightning strikes and other induced transient overvoltage events can cause spikes and surges at much higher voltage levels. Additional protection for receiving devices may be a wise investment for higher risk installation areas. Many transmitters offer transient suppression options that can be integrally mounted onto the terminal strip within the housing. For other transmitters an external protection device may be used. See Figure 3.1.11.3a.

It is not uncommon for a lighting generated transients hitting the output signal line to propagate towards the transmitter and then be reflected back towards the receiving device. This situation may require additional external devices at the receiver.

TIP: External field mounted suppressors may not carry agency certification for explosion proof applications. A transmitter with an integral style suppressor is suggested for these applications.

TIP: For high risk plant sites, transient protection for all critical instrumentation and control devices may be worth considering.

Figure 3.1.11.3a – Terminal Block Transient Suppressor

3.1.12 Safety Certified Transmitters

Safety Instrumented System (SIS) is defined by the IEC 61511 Safety Standard as an instrumented system used to implement one or more safety instrumented functions. An SIS is composed of any combination of sensors (transmitters), logic solvers, and final elements.

A transmitter to be used for a safety function in an SIS must meet certain design and performance criteria and be certified for use in accordance with IEC 61508.

As an example manufacturers specification: “Certification: The 3144P is certified to IEC61508 for single transmitter use in Safety Instrumented Systems up to SIL 2 and redundant transmitter use in Safety Instrumented Systems up to SIL 3. The software is suitable for SIL 3 application.”

The certification process is performed by an approved third party agency. (TUV for example) The transmitter will have a distinctive yellow tag affixed. See Figure 3.1.13b in section 3.1.13.

Tip: A Safety Instrumented Function (SIF) is assigned a Safety Integrity Level SIL) during risk analysis. All of the components of the SIF are considered together in performing a SIL compliance calculation. The result is that, even though the transmitter is certified up to SIL 2 as a single device, the limitations of the sensor and the valve typically demand a redundant configuration to meet a SIL 2 requirement.

As an alternative, a device that has not been certified but that has a long record of proven-in-use safe operation may be used in a SIS at the user’s discretion. This option requires that the user have detailed failure data for a statistically valid sample of the same model device operating under similar operating conditions. Records must be provided showing the hours of operating usage, the operating environment, the type and frequency of failures. Vendor upgrades to new models may require restarting the time clock on the data.

Best practice indicates that designing your system around an IEC 61508 certified instrument avoids the laborious and expensive record keeping for proven-in-use devices. It should be noted that many vendors offer the same basic product for both process control and safety applications. There is benefit to using the same models as are used in the basic process control system (BPCS) to benefit from the history of installation and operation knowledge that already exists as well as spare parts inventory.

TIP: For a more detailed discussion of using transmitters in Safety Instrumented Systems refer to the SIS section 8.3 in the reference list in the appendix.

3.1.13 Tagging

Each instrument installed as a functional part of a control system has a unique identification number. Users frequently want a permanent corrosion resistant tag number affixed to the transmitter. See Figure 3.1.13a.

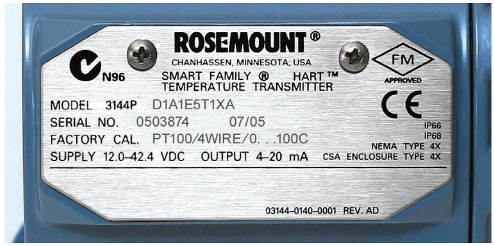


Figure 3.1.13a – Standard Instrument Tag

Most intelligent transmitters also provide for the tag number to be programmed into its electronics – known as a soft tag - so the transmitter is capable of responding to an inquiry sent via the control system or a communicator. This is very useful during commissioning and troubleshooting to enable easy verification of the identity and/ or integrity of each control loop and the functionality of every transmitter. Safety Certified transmitters have a distinctive yellow tag affixed. Figure 3.1.13b

Figure 3.1.13b – Safety Certified Instrument Tagging (Yellow)

3.1.14 Configuration Options

All transmitters must be configured for certain basic variables to operate properly. In many cases, these variables are pre-configured at the factory to default settings. Since these default settings may or may not match the actual loop parameters of your application, user configuration may be required to adjust these variables to the actual process requirements of the specific loop. Configuration may be accomplished in a variety of ways depending on the manufacturer’s options, plant preferences, and/ or system architecture. They include:

- Hand-held field configurator
- Laptop software program with interface
- Local operator interface (LOI) push-buttons
- Asset management system

TIP: For a complete discussion of transmitter configuration, installation, commissioning and maintenance refer to the Engineering and Design in Chapter 4 and the Maintenance and Calibration in Chapter 5 of this handbook.

Options and Features Summary

In summary, regardless of the hostile conditions that might exist at the point of measurement, it is apparent from the descriptions above of available transmitter features and options, a properly specified and configured temperature measurement system can go a long way to ensure that a stable, accurate and reliable measurement is continually reported to the receiving system or device.

3.2 Temperature Sensors

3.2.1 Overview

High process temperature, pressure, and vibration make robust temperature measurement devices a necessity in industrial environments. Accuracy, repeatability, and stability are needed for consistent process control. While several types of temperature sensors may be used, resistance temperature detectors (RTDs) and thermocouples (T/Cs) are most common in the process industry and will be the focus of this section. Temperature measurements comprise the largest segment of all process measurements and can often have the largest impact on production efficiency, quality, and safety. The user must fully understand each application and make the best choice of a temperature measurement system.

We hope that the information and insights presented in this section will provide much of the information required to make informed sensor selections. Refer to Chapter 4 Engineering and Design for further discussion about the implications associated with your choice and guidance in designing your complete temperature system.

3.2.2 History of Sensors

RTD sensor technology used today has its roots dating back over a century. The application of the tendency of electrical conductors to increase their electrical resistance with rising temperature was first described by Sir William Siemens at the Bakerian Lecture of 1871 before the Royal Society of Great Britain. The necessary methods of construction were established by Callendar, Griffiths, Holborn and Wein between 1885 and 1900.

T/C technology is based on the Seebeck Effect. This effect is named after the German physicist Thomas Johann Seebeck (1770–1831), who, in 1826, published the results of experiments done four years earlier that opened up the new field of thermoelectricity. He observed that an electrical current is present in a series circuit of two dissimilar metals, provided the junctions of the two metals are at different temperatures. In a T/C we are using the emf generated by one of the junctions with respect to a reference junction to infer temperature. The Peltier effect, first exhibited by Jean Peltier in 1834, is viewed as the compliment to the Seebeck effect and describes the ability to generate a heat variation due to a voltage difference across a two dissimilar metals at the junction. This phenomenon in one application has been applied as a cooling mechanism for solid state devices. These complimentary effects are generally known as the Peltier-Seebeck effect.

The evolution of indicating, recording, transmitting and controlling instrumentation has been extraordinary. From the early days of vacuum tube operated electrical devices we have progressed through solid state components to the microprocessor powered devices of today offering extraordinary performance and features not even thought of a few years ago. A technology breakthrough in the 1960s fostered the birth of the first two-wire temperature transmitter by what was then Rosemount Engineering Company.

3.2.3 Resistance Temperature Detectors (RTDs)

Resistance temperature detectors (RTDs) are based on the principle that the electrical resistance of a metal increases as temperature increases –

WHAT ARE THE SENSOR LEAD WIRE COLOR STANDARDS THAT SHOULD BE FOLLOWED?

Various standards prescribe color codes for RTD and Thermocouple lead wires and for thermocouple extension wire.

For RTDs refer to:

3.2.3.10 – Lead Wire Colors

3.2.3.14 – RTD International Standards

For Thermocouples refer to:

3.2.4.5 – T/C Lead Wire Color Standards

Table 3.2.4.5a – International Color Coding for Thermocouple Insulation a phenomenon known as thermal resistivity. Thus, a temperature measurement can be inferred by measuring the resistance of the RTD element.

RTD's are constructed of a resistive material with leads attached and usually placed into a protective sheath. The resistive material may be platinum, copper or nickel with the most common by far being platinum because of its high accuracy, excellent repeatability, and exceptional linearity over a wide range and it exhibits a large resistance change per degree of temperature change. Refer to Figure 3.2.3a

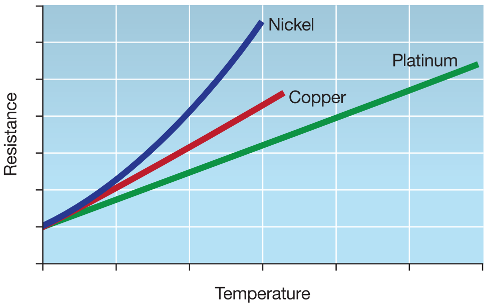


Figure 3.2.3a – Resistance Change vs. Temperature for Common Sensor Materials

The two most common styles of RTD sensors are wire-wound and thin film. Wire-wound RTDs are manufactured either by winding the resistive wire around a ceramic mandrel or by winding it in a helical shape supported in a ceramic sheath – hence the name wire-wound. To manufacture thin film RTD sensors, a thin resistive coating is deposited on a flat (usually rectangular) ceramic substrate.

Copper and nickel are generally used in less critical industrial applications due to limited accuracy and linearity, and relatively narrow temperature ranges.

Nickel elements have a limited temperature range because the amount of change in resistance per degree of change in temperature becomes very non-linear at temperatures over 300 °C. Use of nickel RTDs has declined over the years due to its performance limitations and since the cost of Platinum RTDs is now a very small premium, if any at all.

Copper has a very linear resistance to temperature relationship but, since copper oxidizes at moderate temperatures, it should not be used over 150 °C. Copper RTD's are commonly used in winding temperature measurements of motors, generators and turbines. 10 Ω copper RTDs have been most common over the years but are now giving way to 100 Ω and even 1000 Ω models to get better resolution thus providing a more accurate measurement. Platinum RTDs are also growing in popularity for these applications. Due to the harsh conditions in these windings and the fact that the sensors cannot be replaced without disassembly of the motor, many vendors and users are opting for dual element RTDs and some are using thin-film RTD designs due to their greater tolerance for vibration and subsequent longer life expectancy.

3.2.3.1 Common RTD Characteristics

Industrial sensors are rarely, if ever, used where they are exposed to the environment. They are encased in a metal tube or sheath that is welded closed at one end and that has lead wires protruding from the sealed other end. See Figure 3.2.3.1a and Figure 3.2.3.1b

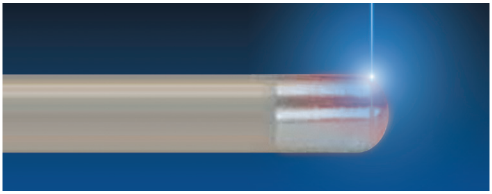


Figure 3.2.3.1a – Laser Welding of Sensor Sheath

Figure 3.2.3.1b – Potting Seal of Rear Sensor Housing

3.2.3.1.1 Sensing Element

The sensing element is located at the tip of the temperature sensor that is exposed to the process temperature. The sensing element responds to temperature by generating a measureable resistance change or a voltage signal that increases as the temperature increases. Sensors can be provided with either one or two elements in one sensor sheath. Dual elements provide a redundant measurement that may be useful for hot back-up, for drift monitoring using a comparison technique, or to provide inputs to two independent controllers or systems (control system or safety system). See Figure 3.2.3.1.1a.

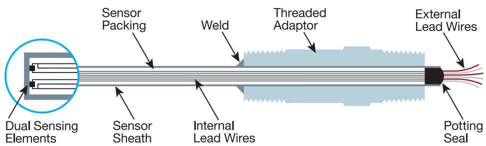


Figure 3.2.3.1.1a – Dual Element RTD

TIP: In some of these applications a case can be made for using two independently installed single sensors instead of a dual element in one sheath. See "Engineering Your Temperature Measurement" in Chapter 4 for further discussion.

3.2.3.1.2 Sensor Sheath

The sensor sheath is made of metal, usually stainless steel (Hastelloy or Inconel is used for certain high temperature applications), and typically contains 2, 4, 6 or 8 conductors connecting the sensing element(s) to the lead wires. A single T/C requires two leads, while a dual T/C requires four leads. A single RTD can have two, three, or four leads, and a dual RTD can have four, six, or eight leads. The sensor sheath protects the element and the conductors from moisture and corrosive and/or abrasive process conditions and helps to shield the signal from electrical noise. To insulate the conductors from each other and from the sheath, the sheath is filled with a compacted finely powdered insulating packing material, typically magnesium oxide (MgO) or aluminum oxide (Al2O3), which surrounds the sensing element and conductors. See Figure 3.2.3.1.2a

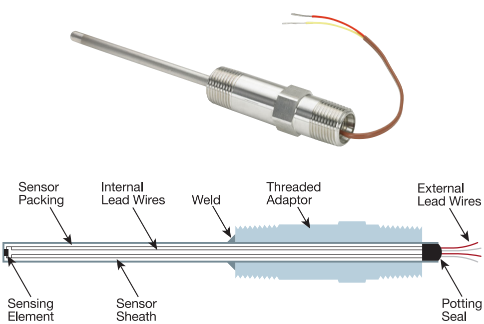


Figure 3.2.3.1.2a – Common Temperature Sensor Characteristics

Sensor sheath diameters vary with the more common dimensions being 6mm (1/4-inch) and 3mm (1/8-inch). The smaller diameters have a faster response time because there is less mass and insulating material. Also, smaller diameters can provide a more accurate measurement due to reduced sheath heat conduction error.

However, most industrial applications use a thermowell for installation, adding considerable mass to the overall assembly thus somewhat mitigating both of these factors. A thermowell is installed into the process making a pressure tight seal and has an internal bore into which the sensor is installed. This allows for easy removal of the sensor for calibration or replacement. See Thermowell chapter 3.3 for more information.

3.2.3.1.3 Lead wires

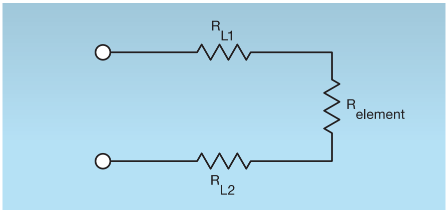
Lead wires are typically stranded, insulated wires which are attached to the conductors that run through the sensor sheath connecting the element to the lead wires. These lead wires are sealed at the end of the sheath and are used to connect the sensor to a terminal block, transmitter or other termination point. The length of these leads varies by vendor and the requirements of the user. Refer to Figure 3.2.3.1b in section 3.2.3.1.

3.2.3.1.3.1 Lead Wire Compensation

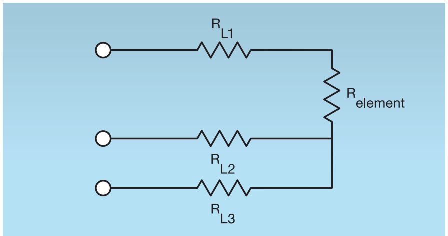
Since the lead wires are part of the RTD circuit, the lead wire resistance needs to be compensated for to achieve the best accuracy. This becomes especially critical in applications where long sensor and/or lead wires are used. There are three lead wire configurations commonly available.

In a two-wire configuration there can be no compensation for lead wire resistance since the lead wires are in series with the element and appear to the transmitter as part of the sensor's resistance causing inherent accuracy degradation. There are few applications where two wire sensors are a good choice. In a three-wire configuration, compensation is accomplished using the third wire with the assumption that it will be the same resistance as the other two wires and the same compensation is applied to all three wires.

Figure 3.2.3.1.3.1b shows the equation for this compensation: *Rmeasurement = RL1 + Relement – RL3*. However, in the real world, there will always be some difference between L1 and L3 due to wire manufacturing irregularities, unequal lengths, loose connections, work hardening from bending, and terminal corrosion.



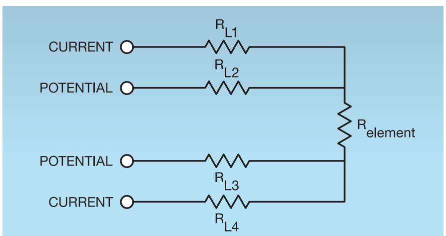
$$R_{measured} = R_{L1} + R_{element} + R_{L2}$$



$$R_{measured} = R_{L1} + R_{element} + R_{L2} - [R_{L2} + R_{L3}]$$

$$= R_{L1} + R_{element} - R_{L3}$$

$$= R_{element} \quad (\text{If } R_{L1} = R_{L3})$$



$$R_{measured} = R_{element}$$

Figure 3.2.3.1.3.1b – Two-, Three-, Four- Wire RTDs with Equations

Since a 100 Ω platinum RTD changes 0.39 Ω per degree C, for every one ohm of difference in the lead wire effective resistance, an error of up to 2.5 °C is produced (1÷0.39). This unbalance error is likely to change unexpectedly and unpredictably over time as corrosion increases and temperature and humidity changes etc. Refer to Figure 3.2.3.1.3.1c

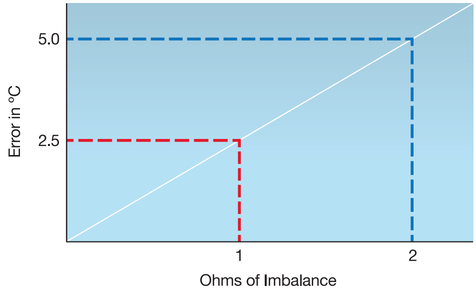


Figure 3.2.3.1.3.1c – Lead Imbalance vs. Error for 3-Wire RTD

A four-wire design is ideal because the lead wire resistance is inconsequential to the measurement. It uses a measurement technique where a very small constant current of about 150 micro amps is applied to the sensor through two leads and the voltage developed across the sensor is measured over the other two wires with a high-impedance and high resolution measuring circuit. In accordance with Ohm's Law the high impedance virtually eliminates any current flow in the voltage measurement leads and therefore the resistance of the leads is not a factor. Refer to Figure 3.2.3.1.3.1b and Figure 3.2.3.1.3.1c.

3.2.3.2 RTD Sensor Construction

Many factors must be considered in the manufacturing of high quality sensors. One method of constructing a wire-wound sensor element uses a very high purity wire that is wound onto a mandrel with a closely matching coefficient of expansion to the wire to minimize element strain effects. Another method is winding the wire in a helical shape that is then placed into a ceramic sheath. Any cement used in the manufacturing must not introduce any strain on the assembly. Assembly must be in a clean room type of environment to eliminate any contamination that could degrade the sensor and increase long term drift. Lead wire material must be selected to be compatible with the range of the sensor and carefully laser welded to the sensor avoiding any thermo-electric junctions. All internal components must be properly supported and strain relieved to eliminate mechanical and thermal induced strain and increase tolerance of shock and vibration. The lower the strain introduced by proper choice of material expansion coefficients; the better will be the repeatability and stability of the sensor assembly. Similar strain relief considerations apply to the manufacture of thin-film elements where a thin platinum film is deposited onto a ceramic substrate. Part of the process also includes annealing and trimming of the sensor resistance to the proper ice point value R0. The process is finished by applying a non-conductive encapsulating material such as cement or glass material to seal the sensor and the welds from potential contamination. Refer to Figure 3.2.3.1.2a and Figure 3.2.3.1b. The completed sensing element is then assembled into a sheath as described above. Both nickel and copper RTDs follow a similar manufacturing process. In general nickel and copper sensors cost slightly less since the price of the metal is far less expensive than ultra pure platinum. However, for thin-film platinum RTDs, such a small amount of platinum is required, that the price advantage of copper or nickel is reduced or eliminated.

3.2.3.2.1 Wire Wound Elements

Mandrel style wire wound elements manufactured as described above are commonly available as 100 Ω up through 1000 Ω with the 100 Ω being the most common choice for industrial applications. They have a range of -200 to 850 °C (-328 - 1562 °F) over which they conform to the 385 alpha curve, and they have a maximum range of -240 to 960 °C (-400 - 1760 °F). See Figure 3.2.3.2.1a

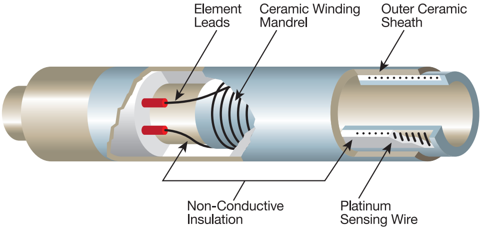


Figure 3.2.3.2.1a – Mandrel Style Wire Wound Element

3.2.3.2.2 Coiled Sensors

Coiled sensors, also called Coil Suspension style sensors, are a variation of wire wound sensors that are designed for rugged applications that also require high accuracy and fast response. They are difficult to manufacture and are only available from a small number of suppliers. Refer to Figure 3.2.3.2.2a

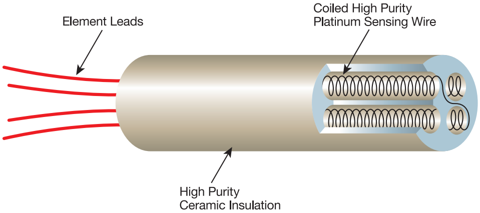


Figure 3.2.3.2.2a – Coiled Wire Wound RTD Element Construction

The element is constructed with a high purity platinum wire that is wound in a helical coil to minimize stress and assure accurate readings over long periods of time. Each helical coil is fully suspended in a high purity ceramic insulator and surrounded by a packed ceramic powder with a binder additive. This construction provides a strain-free sensing element as contrasted with mandrel wire wound or thin film designs where there is always some stress introduced by differences in thermal expansion coefficients between the mandrel or substrate and the platinum element and also from the glass encapsulation that is applied. These coiled elements enhance vibration and shock resistance without interfering with the coil's ability to expand or contract. This is the reason why coiled elements are often a better choice than thin film elements for cryogenic applications.

They are useful over a range of -200 to 1000 °C (-328 - 1832 °F)

3.2.3.2.3 Thin Film Elements

Thin-film elements are manufactured by depositing a thin film of pure platinum on a ceramic substrate in a maze-like pattern. Refer to Figure 3.2.3.2.3a The sensor is then stabilized by a high temperature annealing process and trimmed to the proper R0 value. These compact sensors are then encapsulated with a thin glassy material. The area where the lead wires are attached is given a much more robust glassy encapsulation to ensure mechanical protection and a moisture seal. With their small size and low mass, these sensors are more vibration resistant then a wire-wound style and are often a better choice for such applications.

Due to the difficulties associated with matching the thermal coefficients of expansion of the platinum coating with the substrate material, the range of these sensors is somewhat limited compared to a wire-wound style and is typically -200 to 800 °C. (-328 - 1472 °F)

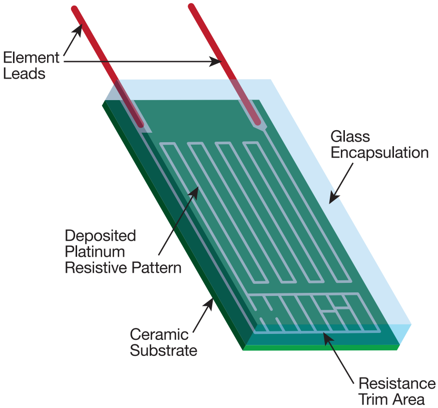


Figure 3.2.3.2.3a – Thin-Film RTD Element Construction

3.2.3.3 Sensor Styles

Different sensor styles exist providing a variety of methods to install the sensor assemblies. Each has distinct attributes for each application and installation practices.

3.2.3.3.1 Capsule Style

The capsule style is simply a sensor sheath with lead wires. Capsules are commonly used with compression fittings and can be cost-effective when environmental conditions such as high pressure or temperature are not a concern.

3.2.3.3.2 Threaded Style

The threaded style is a capsule style with a threaded adaptor to provide a connection to the process and connection head or housing. The benefit of the threaded style is the ability to install it directly into a process or thermowell without an extension. Three common styles are:

General purpose weld – the capsule is welded to a threaded adapter creating a process seal. When conditions allow, it can be directly immersed into the process without a thermowell to improve response time. The seal is limited by the thread connection and therefore has lower pressure ratings than can be achieved using welded or flanged thermowells. (See thermowell chapter for details) General purpose weld styles are not recommended for use with thermowells because the sensor tip will not touch the bottom of the well thus creating a thermal lag. See Figure 3.2.3.1.2a.

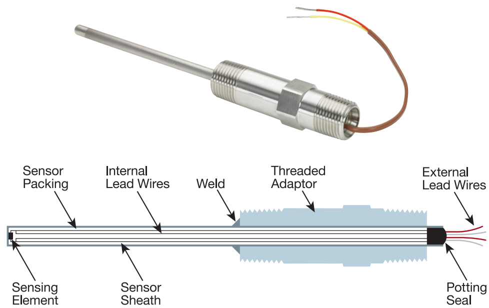


Figure 3.2.3.1.2a – General Purpose Welded Adapter Style

Spring loaded – a spring located in the threaded adaptor allows the capsule to travel, ensuring contact with the bottom of a thermowell. This spring style provides continuous contact to the bottom of the well which provides better tolerance of vibration and significantly faster speed of response of the measurement. See Figure 3.2.3.1.2b

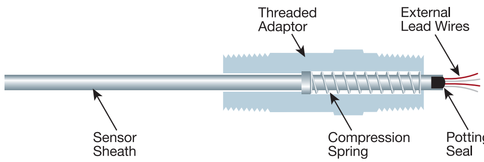


Figure 3.2.3.1.2b – Spring Loaded Threaded Style

Bayonet spring loaded –a bayonet spring loaded style is similar to spring loaded style but allows removal of the capsule without disassembly of the threaded adapter from the thermowell. This saves twisting of the leads and potential damage when removing a threaded type. See Figure 3.2.3.1.2c.

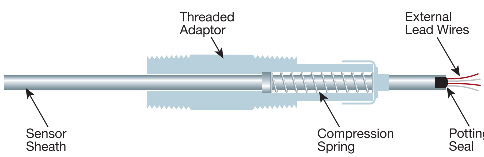


Figure 3.2.3.1.2c – Bayonet Style Spring Loaded Sensor Assembly

3.2.3.3.3 DIN Style

The DIN style is a sensor capsule with a circular plate that provides an effective mounting method for connection heads or housings. Refer to Figure 3.2.3.3.3a. The benefit of the DIN style is the ability to install and replace the sensors without removing the connection head or housing from the process as the sensor is inserted through the housing instead of threaded into the bottom. All DIN styles are spring loaded. Two common styles are:

3.2.3.3.3.1 – ***Flying Leads –*** A DIN plate is attached to the end of the capsule. The flying lead style is most often used with a head mount transmitter. Spring loading is provided by the mounting screws of the transmitter.

3.2.3.3.3.2 – ***Terminal Block –*** A DIN plate with a terminal block is attached to the end of the capsule. The terminal block style is most often used in remote mount configurations where the transmitter is located elsewhere and wires are run between the sensor and the transmitter. Spring loading is provided by the mounting screws of the terminal block or transmitter.

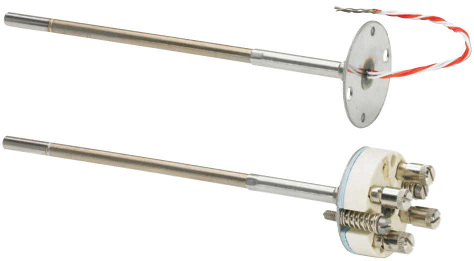


Figure 3.2.3.3.3a – DIN Mount Sensors – Flying Leads – Terminal Block

3.2.3.4 Extensions

Sensors can include extensions of various lengths to accommodate different insulation thicknesses and to distance the transmitter from high process temperatures that may affect the transmitter electronics. Extensions can be a combination of unions, nipples, and/or couplings. See Figure 3.2.3.4a.

Figure 3.2.3.4a – Typical Nipple – Union Extension

3.2.3.5 Mounting Options

Temperature sensors may be either immersed in the process fluid or surface-mounted. The mounting selection depends on the measurement application, process conditions, and environmental constraints.

3.2.3.5.1 Immersion Mounting

As the name suggests, immersion temperature sensors are inserted into the process medium; furthermore, they are typically installed into a thermowell for protection against process conditions. Refer to section 3.3 for more detail. Refer to Figure 3.2.3.5.1a and Figure 3.1.3.5b. Depending on sensor construction and process conditions, some sensors can be inserted directly into the process medium. While this is less expensive and provides faster response, it requires a process shutdown and draining of the process for removal of the sensor for calibration or replacement.

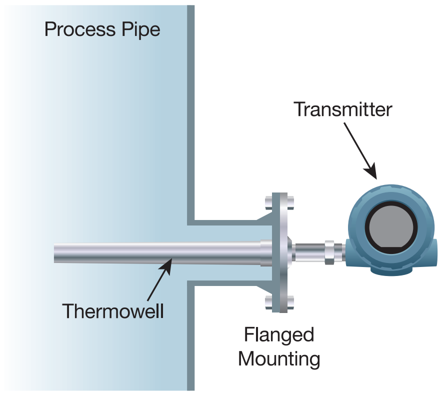


Figure 3.2.3.5.1a – Transmitter Assembly Pipeline Installation

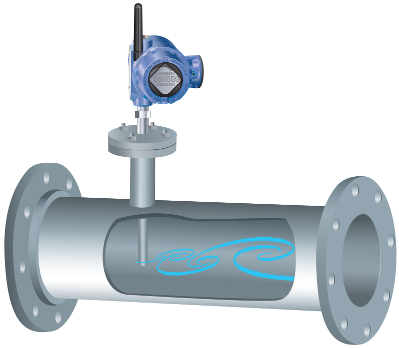


Figure 3.1.3.5b – Wireless Integral Mount Pipeline Installation

3.2.3.5.2 Surface Mounting

Surface mounting is an efficient and convenient installation method often used when it is impractical or impossible to insert a sensor assembly into the process. For example, this situation may exist because of frequent use of a "pig" to remove process material that builds up in the piping and the pig cannot pass by obstructions such as a thermowell protruding into the pipe. Refer to Figure 3.2.3.5.2a. Another application is to provide a new measurement where an expensive process shutdown would be required to install a system in a new thermowell. See Thermowell Section 3.3 for more information.

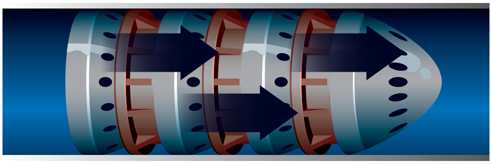


Figure 3.2.3.5.2a – Piping Cleaning Pig

However, surface measurement is only as reliable as the temperature on the surface of the pipe or vessel. In general, the goal is to maximize heat conduction from the pipe or vessel surface to the sensing element. Sensors can be mounted with adhesives, screws, clamps, or welds and recognizing that good thermal contact is necessary. Refer to Figure 3.2.3.5.2b. Thermal insulation is used to minimize the loss of heat energy from the surface of the pipe to its surroundings and should cover the sensor and the lead wires for some distance to minimize any conduction heat losses to the leads. This helps to ensure that that the sensor is at, or as close as possible to, the actual surface temperature of the pipe which is assumed to be at the process fluid temperature. Process fluid flow rate and rate of temperature change significantly influence this assumption. Differing thermal coefficients of expansion of the pipe and the mounting assembly must also be considered to minimize stress to the sensor that would degrade the measurement or even destroy the sensor.

Figure 3.2.3.5.2b – Surface Mount Sensors - Pipe Clamp

Tip: For a more detailed discussion of the application of surface mounted sensors refer to the Engineering section 4.2.2.4 of this handbook.

3.2.3.6 Factors Affecting RTD Performance

3.2.3.6.1 Resistance - Alpha Values

RTD elements are characterized by their Temperature Coefficient of Resistance (TCR) also referred to as its alpha value. The IEC 60751-2008 standard defines these values for platinum element types. Refer to Figure 3.2.3.6.1a.

The alpha value is the temperature coefficient for that specific material and composition. Copper elements have a different alpha value than platinum elements, and platinum elements themselves can vary depending on the purity of the platinum and any alloy content. Alpha values define sensor interchangeability. Various sensors with the same alpha value guarantees that the resistance vs. temperature relationship will be the same for each sensor within a specified precision specification. When replacing a sensor, the user should ensure that the same material with the same resistance and alpha value, e.g. Pt100: $\alpha = 0.00385$ is used.

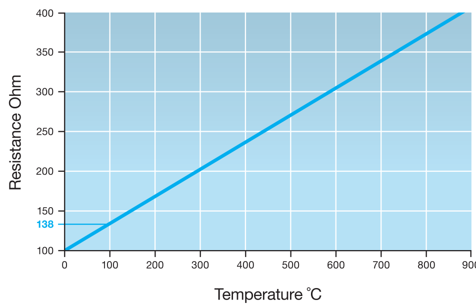


Figure 3.2.3.6.1a – Temperature Coefficient of Resistance (TCR) of a Pt100

3.2.3.6.1.1 The Alpha Equation defines the Alpha Value:

Alpha = (R100 – R0) ÷ 100 R0

Where R0 is the resistance of the sensor at 0 °C and R100 is the resistance of the sensor at 100 °C

Platinum RTDs are available with alpha values ranging from 0.00375 to 0.003927. The highest alpha value indicates the highest purity platinum, and is mandated by the International Temperature Scale of 1990 (ITS-90) for standard (Laboratory) grade platinum thermometers.

There are no technical advantages of one alpha versus another in practical industrial applications. The 0.00385 platinum is the most popular and most commercially available worldwide standard and is available in various styles including wire-wound and thin-film elements from 100 Ω to 1000 Ω. In most cases, all the user needs to know about the alpha value is that it must be properly matched when replacing RTDs or connecting them to instruments.

3.2.3.7 Self Heating

Self Heating is caused when the sensing current from the transmitter is passed through an RTD sensing element. Heating is caused according to the I2 R principle contained in Joule's Law which states "power, increases as the square of the current through the windings and in proportion to the electrical resistance of the conductors." Since the current supplied by most microprocessor based transmitters is very small; typically 200 to 250 micro amps (µamps), the heat produced is also very small and will have a negligible effect on the measurement accuracy.

TIP: Many older analog circuitry transmitters have a significantly higher excitation current that will cause significantly more sensor self heating and related measurement error. For high-accuracy applications a wise user will consider an upgrade to a microprocessor-based transmitter.

3.2.3.8 Sensor Response Time

The Response Time of a sensor is the time required for the output of a sensor to change by a specified percentage of an applied step change in temperature for a specific set of conditions. Note that there are different standards for testing response time that will produce widely varying results. Only if the sensors are tested to the same standard can the response time of different sensors tested under identical conditions be compared. However, any change in such conditions such as fluid density, temperature, or flow rate will yield alternative results. For example the response time will be much slower in a gas than it will be in a fast moving liquid.

Response Time is usually stated in seconds and the percentage at which the time was recorded is indicated by the number next to the response time value "t". For example t(0.5) means the response time value for 50% of the step change and t(0.9) means the response time value for 90% of the step change. See Figure 3.2.3.8a.

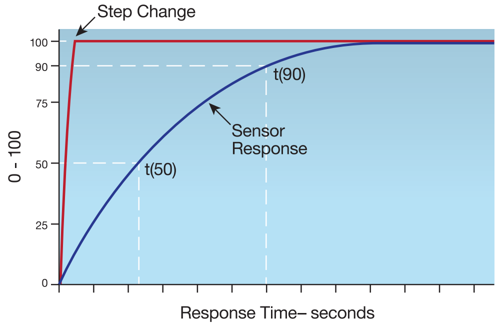


Figure 3.2.3.8a – Typical Sensor Response Time

Factors that affect response time include the thermal conductivity of the fill material between the inside wall of the thermowell and the sensor sheath, the distance of the gap between the sensor tip and the bottom of the well bore, the tip width, the well thickness and the positioning in the flow stream. Referring to Figure 3.2.3.8b ideally the "x" and" y" dimensions should approach zero and the "B" and "t" dimensions should be as small as proper well design for the application will permit. Using a spring-loaded sensor helps to minimize the "x" distance. Proper insertion length of the well into the process should be determined to maximize thermal response. Refer to 3.3.7.0 for more detail.

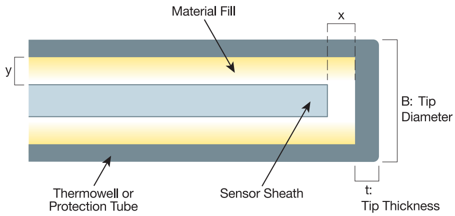


Figure 3.2.3.8b – Factors Affecting Response Time

3.2.3.9 Hysteresis

Hysteresis is a phenomenon that results in a difference in a sensor's output when approaching the same value from two different directions. For example, when the output is compared at a particular point after an increase in temperature above that point and then returning to that same point, it will be different than the output if the temperature is reduced below the point and then returned. In laboratory grade or standard RTDs there is negligible hysteresis since there is minimal contact between the platinum element and the supporting media due to its coiled suspension design. These are very high precision and very high cost sensors used as calibration standards requiring the utmost care to prevent shock damage. An industrial grade sensor does have hysteresis error due in part to its inherent rugged design with the encapsulation essentially bonding the platinum to the supporting mandrel or substrate. The difference in thermal coefficients of expansion of the different materials produces a drift error. In 1982, D.J. Curtis of Rosemount investigated different RTD designs and found that wire wound styles are the best with typical hysteresis spec of 0.008% and that thin film styles exhibited greater typical hysteresis of 0.08%. See Figure 3.2.3.9a. For most applications this is negligible.

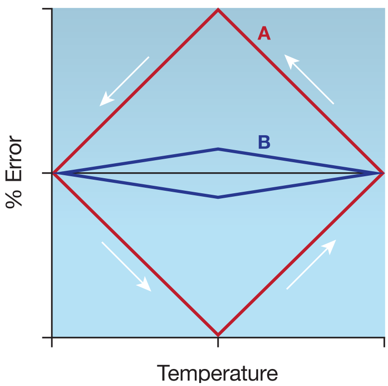


Figure 3.2.3.9a – Hysteresis for Thin Film (A) and for Helical Coil Wire-Wound Elements (B)

3.2.3.10 Lead Wire Colors

Lead wire colors are defined in the IEC 60751-2008 standard where all wire colors are shown as in the following figure. Refer to Figure 3.2.3.10a. However, lead wire colors may vary with individual manufacturers.

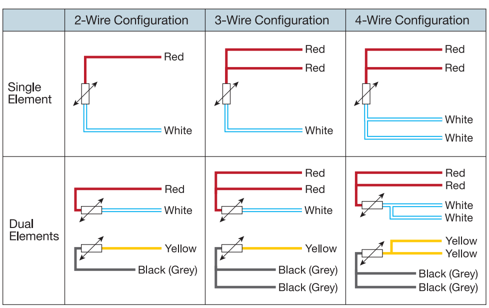


Figure 3.2.3.10a – RTD Lead Wire Colors per IEC 60751

3.2.3.11 RTD Accuracy/Interchangeability

When comparing accuracy / interchangeability, a ± percentage is only valid at the ice point. To determine the tolerance at the intended operating temperature, a tolerance with an equation should be provided by the vendor as is shown in Figure 3.2.11a.

Tolerance Class	Temperature Range of Validity °C		Tolerance Values* °C
	Wire Wound Resistors	Film Resistors	
AA	-50 to +250	0 to +150	± (0.1 + 0.0017 | t |)
A	-100 to +450	-30 to +300	± (0.15 + 0.002 | t |)
B	-196 to +600	-50 to +500	± (0.3 + 0.005 | t |)
C	-196 to +600	-50 to +600	± (0.6 + 0.01 | t |)
ASTM E1137	Grade A	–	± (0.13 + 0.0017 | t |)
ASTM E1137	Grade B	–	± (0.25 + 0.0042 | t |)

* | t | Modulus of temperature in °C without regard to sign.

Figure 3.2.11a – Platinum RTD Accuracy Classes per IEC 60751 and ASTM E1137

There are several classes of RTD accuracy / interchangeability that define the relationship of the amount of error allowed for a given RTD type at a given temperature as compared to the standard. Refer to Figure 3.2.11a The maximum allowable sensor interchangeability error at a given process temperature is defined by the two IEC 60751 standard classifications; Class A and Class B. These classifications are used to identify platinum RTD interchangeability tolerance wherein the Class B sensors have about twice as big of a tolerance band as a Class A sensor. Refer to Figure 3.2.11b.

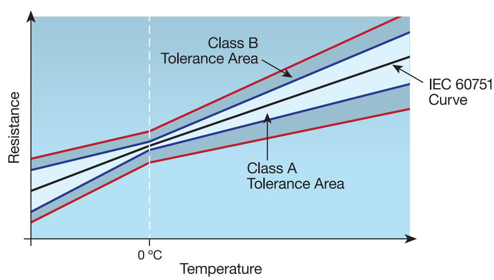


Figure 3.2.11b – IEC 60751 Ideal vs. Class A vs. Class B Tolerance Bands

Note also that the tolerance or error band widens for temperatures above or below the ice point R0. Refer to Figure 3.2.11c. Typical manufacturer's data for a particular sensor is provided in a product data sheet. Refer to Figure 3.2.11d There are other classes defined as shown in Figure 3.2.11a however Class A and B (Or Grade A and B for the ASTM E1137 standard) are most frequently used in the process industries.

Element Interchangeability in °C				
Temp °C	Class B	Class A	Class AA (1/3 B)	Class 1/10 DIN
-196	1.28	–	–	–
-100	0.80	0.35	–	–
-50	0.55	0.25	0.18	–
-30	0.45	0.21	0.15	–
0	0.30	0.15	0.10	0.03
100	0.80	0.35	0.27	0.80
200	1.30	0.55	0.43	–
250	1.55	0.65	0.52	–
300	1.80	0.75	–	–
400	2.30	0.95	–	–
450	2.55	1.05	–	–
500	2.80	–	–	–
600	3.30	–	–	–

Figure 3.2.11c – Wire wound RTD Element Interchangeability by Class vs. Temperature

Series 78 Interchangeability	
Standard Series 78 IEC 60751 Class B	**Temperature**
±0.80 °C (±1.44 °F)	-100 °C (-148 °F)
±0.30 °C (±0.54 °F)	0 °C (32 °F)
±0.80 °C (±1.44 °F)	100 °C (212 °F)
±1.80 °C (±3.24 °F)	300 °C (572 °F)
±2.30 °C (±4.14 °F)	400 °C (752 °F)
Series 78 IEC 60751 Class A Option	**Temperature**
±0.35 °C (±0.63 °F)	-100 °C (-148 °F)
±0.15 °C (±0.63 °F)	0 °C (32 °F)
±0.35 °C (±0.63 °F)	100 °C (212 °F)
±0.75 °C (±1.35 °F)	300 °C (572 °F)
±0.95 °C (±1.71 °F)	400 °C (752 °F)

Figure 3.2.11d – Specific Product Interchangeability Data

3.2.3.11.2 Sensor Interchangeability Error

Sensor Interchangeability Error is defined as the difference between the actual RTD curve and the ideal RTD curve. Refer to Figure 3.2.11b and Figure 3.2.3.11.2a. The IEC standard uses only the ice point resistance R0 and the sensor Alpha Number to define an approximation of an ideal curve. However, due to manufacturing tolerance variation and the degree of purity of the platinum, each individual sensor will have its own unique curve that will vary slightly from the ideal curve. IEC 60751 defines minimal acceptable accuracy tolerance for conformance to the standard for each class of sensor over a range of temperatures.

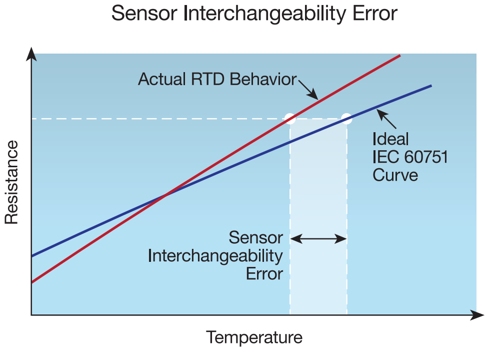


Figure 3.2.3.11.2a – Sensor Interchangeability Error

The IEC standard defines a PT100 sensor output using a 4th-order equation that was developed by Hugh Longbourne Callendar and M.S. Van Dusen, and is today known as the Callendar-Van Dusen (CVD) equation. Refer to Figure 3.2.3.12a. The CVD equation can be used to define this unique RTD curve by finding the CVD constants using a calibration or characterization procedure. In this procedure an RTD's resistance is measured in several different precision controlled temperature baths. The data collected are fit to a fourth-order curve, from which the four Callendar-Van Dusen constants are determined:

3.2.3.12 The Callendar-Van Dusen Equation

The Callendar-Van Dusen equation offers an alternative calibration technique to that in the IEC 60751 standard. It is used in transmitter-sensor matching to create a curve that closely approximates an RTD's resistance versus temperature relationship. This curve can be generated for any RTD by plugging the RTD's specific four constants into the Callendar-Van Dusen equation, which is programmed into many smart transmitters. Refer to Figure 3.2.3.12a. In this way, the transmitter uses the actual RTD curve rather than an ideal curve to translate the sensor's resistance signal into a temperature value thus providing extraordinary system accuracy.

While this matching is typically not required for all process measurements, it is the clear choice for those measurements requiring the best possible accuracy.

$$R_t = R_o + R_o\alpha[t - \delta(0.01t - 1)(0.01t) - \beta(0.01t - 1)(0.01t)^3]$$

Where:

R_t = Resistance (ohms) at Temperature t (°C)

R_o = Sensor-Specific Constant (Resistance at t = 0 °C)

α = Sensor-Specific Constant

δ = Sensor-Specific Constant

β = Sensor-Specific Constant (0 at t > 0 °C, 0.11 at t < 0 °C)

Figure 3.2.3.12a – Callendar-Van Dusen Equation

TIP: Temperature sensor-transmitter assemblies can be visualized as "good - better - best" where a transmitter used with a Class B sensor is "good"; a transmitter used with a Class A sensor is "better" and a transmitter matched to a sensor using the x constant method is "best". There is little, if any, benefit to paying the extra cost for a Class A sensor when using the CVD method. Class B sensors will provide about the same accuracy results. See Figure 3.2.3.12b.

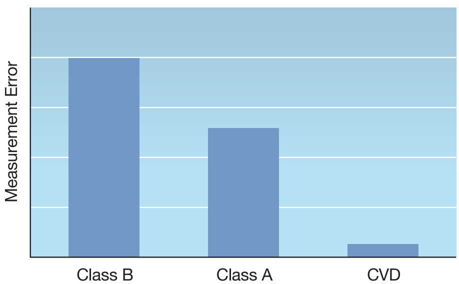


Figure 3.2.3.12b – Good - Better - Best: Calibration Comparison of Systems Using a Class B Sensor vs. Using a Class A Sensor vs. Using the CVD Method

3.2.3.13 RTD Stability - Drift

Stability is related to the amount of the sensor drift and is the relationship of a sensor's original resistance curve to its curve after being in service. Drift rates published by a manufacturer for a particular sensor must be assumed to be applicable in a controlled "laboratory-like" environment. The actual drift in an industrial application may be much different.

A variety of influencing factors affect stability in a platinum sensor used in industrial applications and it will certainly not be as good as published drift rates at 0.0 °C (32.0 °F) in a controlled environment. Thermal and mechanical stresses cause physical changes in the crystalline structure of the platinum causing a distortion in the normal resistance vs. temperature curve. Chemical reactions involving the platinum and impurities as well as migration of internal materials can also affect a sensor output. A shunting effect due to insulation resistance deterioration is another influencing occurrence. Operating at higher temperatures increases the speed of these reactions thus causing increased drift.

The drift caused by these conditions is not normally catastrophic and may be considered to be very low when operated in temperatures below 300 °C (572 °F). (Typically < ±0.05 °C (0.09 °F) change to R0.) Operation at higher temperatures greatly increases the drift rate. For example, at 500 °C (932 °F) the drift can be as much as 0.35 °C (0.63 °F) after 1000 hours. Refer to Figure 3.2.3.13a.

Repeated cycling causes a small drift contribution that increases with the number of accumulated cycles and the maximum temperature reached in each cycle. This contribution is typically negligible.

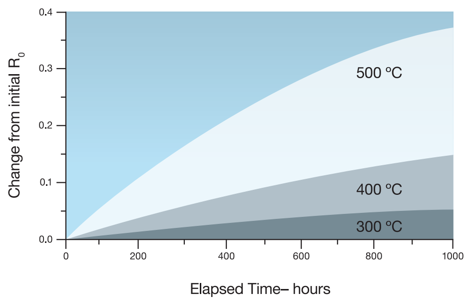


Figure 3.2.3.13a – Shift of R_0 vs. Time vs. Temperature

3.2.3.14 RTD International Standards

Several international standards define the relationship between resistance and temperature for RTD sensors. Over the years, and especially before 1990, there were many different "standards" for industrial RTDs. Many had unique coefficients, due to unique doping of the platinum. Today there are only two that are common: ASTM 1137 (American) and IEC 60751 (International). The International Electrotechnical Commission IEC 60751 standard describes the ideal relationship between the resistance of platinum RTDs and the temperature being measured. Refer to Figure 3.2.3.14a. Many national standards are based on the IEC standard. Released in 2008, IEC60751-2008 includes new tolerance classes, specifies wire colors for RTDs as described above, and expands the range of alpha (α) values used in the Callendar-Van Dusen equation.

IEC 60751 is equivalent to and supersedes the DIN 43760 and the BS-1904 standards.

IEC 60751 also is equivalent to the Japanese standard JS-C1604

American Society for Testing and Materials (ASTM) E1137. This standard applies to platinum RTDs with an average temperature coefficient of resistance of 0.00385 %/ °C between 0 and 100 °C and nominal resistance at 0°C of 100 Ω or other specified value. This specification covers platinum RTDs suitable for all or part of the temperature range between -200 to 650 °C.

JJG 229 is a Chinese standard also known as "Regulations of Industry Platinum and Copper Resistance Thermometers". It is similar to the IEC 60751 standard.

International Standards	
Standard	**Comment**
IEC 60751	Defines Class A and B performance for 100Ω 0.00385 alpha Pt RTDs.
DIN 43760	Equivalent to IEC 60751.
BS-1904	Equivalent to IEC 60751.
JIS C1604	Equivalent to IEC 60751. Adds 0.003916 alpha.
ITS-90	Defines temperature scale and transfer standard.

Figure 3.2.3.14a – International Standards Requirements Comparison

3.2.4 Thermocouples

3.2.4.1 Overview

A thermocouple (T/C) is a closed-circuit thermo-electric temperature sensing device consisting of two wires of dissimilar metals joined at both ends. A current is created when the temperature at one end or junction differs from the temperature at the other end. This phenomenon is known as the Seebeck effect, which is the basis for thermocouple temperature measurements.

One end is referred to as the hot junction whereas the other end is referred to as the cold junction. The hot junction measuring element is placed inside a sensor sheath and exposed to the process. The cold junction, or the reference junction, is the termination point outside of the process where the temperature is known and where the voltage is being measured. (e.g. in a transmitter, control system input card or other signal conditioner.) Refer to Figure 3.2.4.2a.

According to the Seebeck effect, a voltage measured at the cold junction is proportional to the difference in temperature between the hot junction and the cold junction. This voltage may be referred to as the Seebeck voltage, thermoelectric voltage, or thermoelectric EMF. As the temperature rises at the hot junction, the observed voltage at the cold junction also increases non-linearly with the rising temperature. The linearity of the temperature-voltage relationship depends on the combination of metals used to make the T/C.

3.2.4.2 Cold Junction Compensation (CJC)

The voltage measured at the cold junction correlates to the temperature difference between the hot and cold junctions; therefore, the temperature at the cold junction must be known for the hot junction temperature to be calculated. This process is known as "cold junction compensation" (CJC). CJC is performed by the temperature transmitter, T/C input cards for a control system, alarm trips, or other signal conditioner. Ideally the CJC measurement is performed as close to the measurement point as possible because long T/C wires are susceptible to electrical noise and signal degradation. Refer to Figure 3.1.2.4.3a.

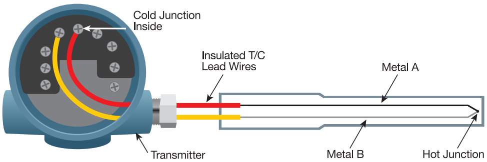


Figure 3.1.2.4.3a - Cold Junction Compensation

Performing an accurate CJC is crucial to the accuracy of the temperature measurement. The accuracy of the CJC is dependent on two things; the accuracy of the reference temperature measurement and the proximity of the reference measurement to the cold junction. Many transmitters use an isothermal terminal block (often made of copper) with an imbedded precision thermistor, an RTD or an integrated circuit transistor to measure the temperature of the block.

TIP: Refer to the "Connecting to the Control System" section 4.2.4.0 for a detailed discussion of why to use field transmitters vs. direct wiring to a control room.

3.2.4.3 Thermocouple Manufacturing

The process begins with the choice of high quality wire of the materials required for the T/C type being made. The wires are joined by various methods including twisting, clamping, soldering, brazing, and various types of welds (e.g., bead and butt). For best performance, the hot junction must be mechanically sound, electrically continuous, and not poisoned by the chemical ingredients of the welding or brazing materials. For premium grade T/Cs, more care is given to the selection of the wire grade and control of the manufacturing process. Refer to Figure 3.2.4.3a.

Tip: Twisted junction method is highly subject to rapid degradation and is not recommended.

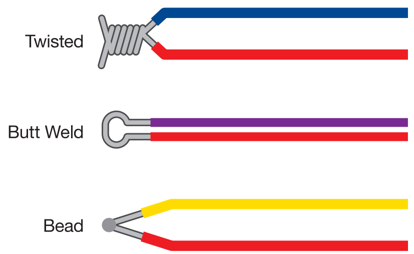


Figure 3.2.4.3a – Hot Conjunction Methods

3.2.4.3.1 Junction Types

T/C Junctions are manufactured in different configurations each with benefits for specific applications. Junctions can be grounded or ungrounded, and dual element thermocouples can be isolated or non-isolated. Refer to Figure 3.2.4.3.1a.

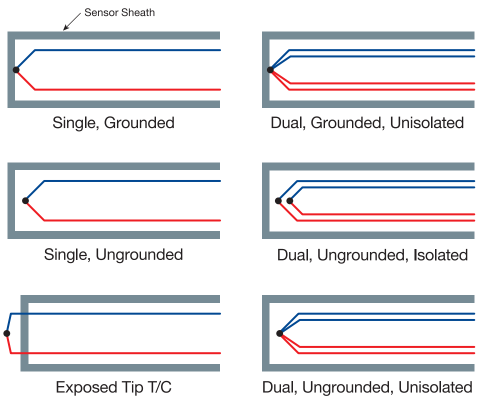


Figure 3.2.4.3.1a – Hot Junction Configurations

Grounded T/C junctions are formed when the thermocouple junction is connected to the sensor sheath. Grounded junctions have better thermal conductivity, which in turn produce the quickest response time. However, grounding also makes thermocouple circuits more vulnerable to electrical noise, which can corrupt the thermocouple voltage signal unless the measurement instrument provides isolation. (All high quality transmitters and I/O cards offer galvanic isolation as a standard feature.) The grounded junction may also be more prone to poisoning over time.

Ungrounded junctions exist when the T/C elements are not connected to the sensor sheath but are surrounded with insulating powder. Ungrounded junctions have a slightly slower response time than grounded junctions but are less susceptible to electrical noise.

Exposed junction T/Cs have the hot junction extending past the sealed end of the sheath to provide faster response. The seal prevents intrusion of moisture or other contaminants into the sheath. These are typically applied only with non-corrosive gases as might be found in an air duct.

3.2.4.3.2 Dual Element T/Cs

Dual element T/Cs are available in three different configurations. Refer to Figure 3.2.4.3.1a.

Isolated configurations exist when two independent T/C junctions are placed inside one sheath. Isolated junctions may not read identical temperatures but can identify drift due to poisoning of one of the elements. If one junction fails, the second junction is not necessarily affected.

Un-isolated configurations exist when two T/C junctions are placed inside one sheath and all four T/C wires are mechanically joined. Un-isolated junctions measure identical temperature to increase the integrity of the measurement point. However, if one junction fails, it is likely that both junctions will fail at the same time.

3.2.4.4 Thermocouple Types

There are many types of T/C that use various metal combinations. These combinations have different output characteristics that define the applicable temperature range it can measure and the corresponding voltage output. Refer to Figure 3.2.4.4a and Table 3.2.4.4b. The higher the magnitude of the voltage output the higher the measurement resolution which increases repeatability and accuracy. There are tradeoffs between measurement resolutions and temperature ranges which suits individual T/C types to specific ranges and applications.

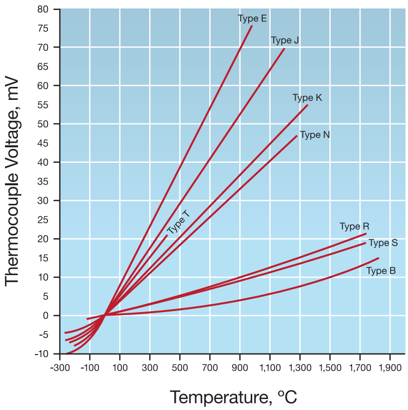


Figure 3.2.4.4a – T/C emf vs. Temperature Curves for Popular T/C Types

ANSI Letter Design	Leg	Metallic Composition	Melting Point °C	Melting Point °F	Potential Temperature Range
B	P	Platinum – 30% Rhodium	1825	3320	0 to 1820 °C 32 to 3308 °F
	N	Platinum – 6% Rhodium			
E	P	Chromel®	1220	2230	-270 to 1000 °C -454 to 1832 °F
	N	Constantan			
J	P	Iron	1220	2230	-200 to 1200 °C -328 to 2192 °F
	N	Constantan			
K	P	Chromel®	1400	2550	-270 to 1372 °C -454 to 2501 °F
	N	Alumel®			
N	P	Nicrosil	1340	2440	-270 to 1300 °C -454 to 2372 °F
	N	Nisil			
R	P	Platinum – 13% Rhodium	1770	3215	-50 to 1768 °C -58 to 3214 °F
	N	Pure Platinum			
S	P	Platinum – 10% Rhodium	1770	3215	-50 to 1768 °C -58 to 3214 °F
	N	Pure Platinum			
T	P	Copper	1080	1980	-270 to 400 °C -454 to 752 °F
	N	Constantan			

P = Positive Leg, N = Negative Leg
® Trademark of Hoskins Mfg.

Table 3.2.4.4b – Detailed Thermocouple Data Chart

WHAT ARE THE THERMOCOUPLE TEMPERATURE RANGES?

There are many types of T/C that use various metal combinations. These combinations have different output characteristics that define the applicable temperature range it can measure and the corresponding voltage output. The higher the magnitude of the voltage output the higher the measurement resolution which increases repeatability and accuracy. There are tradeoffs between measurement resolutions and temperature ranges which suits individual T/C types to specific ranges and applications.

There are T/C types that can measure temperatures as low as - 270 °C (-464 °F) and other types that can measure up to 1768 °C (3214 °F).

Refer to:

3.2.4.4 – Thermocouple Types

Table 3.2.4.4b – Detailed Thermocouple Data Chart

3.2.4.4.1 Type K Chromel – Alumel

- Chromel® is 90% nickel and 10% chromium and Alumel® is an alloy consisting of 95% nickel, 2% manganese, 2% aluminum and 1% silicon.
- Type K is one of the most common general purpose thermocouple with a sensitivity of approximately 41 µV/ °C.
- The Chromel® is positive relative to Alumel®.
- It is inexpensive, and its potential range is -270 °C to +1372 °C (-454 °F to +2501 °F) and is relatively linear.
- The nickel constituent is magnetic and, as other magnetic metals, will undergo a deviation in output when the material reaches its Curie point which occurs at around 350 °C (662 °F) for type K thermocouples. The Curie point is where a magnetic material undergoes a dramatic shift in its magnetic properties and causes a drastic shift to the output signal.
- It may be used in continuously oxidizing or neutral atmospheres.
- Most usage is above 538 °C (1000 °F)
- Exposure to sulphur contributes to premature failure.

- Operation at certain low oxygen concentrations causes an anomaly called preferential oxidation of chromium in the positive leg which causes a condition referred to as 'green rot' which generates large negative calibration drifts that are most serious in the 816 to 1038 °C (1500 to 1900 °F) range. Ventilation or inert-sealing of the protection tube can prevent / mitigate this condition.
- Cycling above and below 1000 °C (1800 °F) is not recommended due to alteration of the output from hysteresis effects.

TIP: Historically it has been suggested to use type K unless you had a reason not to.

3.2.4.4.2 Type J Iron – Constantan

- Type J thermocouples have a more restricted potential range than type K of -200 to +1200 °C (346 to 2193 °F), but higher sensitivity of about 50 µV/ °C.
- It is very linear in the range of 149 to 427 °C (300 to 800 °F) and becomes brittle below 0 °C (32 °F)
- At the Curie point of the iron 770 °C (1418 °F) an abrupt and permanent change in the output characteristic occurs, which determines the practical upper temperature limit.
- The iron is subject to oxidation at higher temperatures above 538 °C (1000 °F) which adversely affects its accuracy. Only heavy gauge wire should be used in these conditions.
- Type J is suitable for use in vacuum, reducing, or inert atmospheres.
- It will have reduced life if used in an oxidizing atmosphere.
- Bare elements should not be exposed to sulphur carrying atmospheres above 538 °C (1000 °F)

3.2.4.4.3 Type E (chromel/constantan)

- Chromel is an alloy of 90% nickel and 10% chromium and is the positive lead
- Constantan is a alloy usually consisting of 55% copper and 45% nickel
- Type E has a potential range of -270 to 1000 °C (-454 °F to 1832 °F)
- It is non-magnetic and has the highest output voltage vs. temperature change of any standard type (68 µV/ °C)
- It also has a tendency to drift more than the other types.
- It is recommended for continuously oxidizing or inert atmospheres.
- Its limits of error have not been established for use below zero.

3.2.4.4.4 Type T (copper/copper-nickel)

- Type T has a sensitivity of 38 µV/ °C and has a potential range of from -270°C to 400°C (-454 °F to 752 °F)
- They can be used in oxidizing, reducing or inert atmospheres as well as in a vacuum
- They exhibit a high resistance to moisture corrosion.
- They demonstrate a good linearity and are typically used from very low (cryogenic) to medium temperature ranges.

3.2.4.4.5 Type N (Nicrosil – Nisil)

- Nicrosil is a nickel alloy containing 14.4% chromium, 1.4% silicon, and 0.1% magnesium and is the positive lead
- Nisil is an alloy of nickel alloyed with 4.4% silicon
- The type N thermocouple is the newest design to have been approved by the international standards and is in ever increasing use throughput the world.
- These alloys allow the type N to achieve considerably higher thermoelectric stability than the base-metal types E, J, K and T.
- Type N thermocouples have a sensitivity of 39 µV/ °C and a potential range of from -270 °C to 1300 °C (-454 °F to 2372 °F)
- Type N thermocouples have been used reliably for extended periods of time at temperatures up to at least 1200 °C (2192 °F)
- Some studies have shown that, in oxidizing atmospheres, the thermoelectric stability of the type N thermocouple is about the same as that of the noble-metal thermocouples of ANSI types R and S up to about 1200 °C (2192 °F)
- Type N thermocouples should not be placed in vacuums or reducing or alternating reducing / oxidizing atmospheres.

3.2.4.4.6 Types R and S

- Type R (platinum-13% rhodium / platinum) and type S (platinum-10% rhodium / platinum) have a potential range of from -50 to1768 °C (58 °F to 3214 °F)
- They both have a sensitivity of about 10 µV/ °C and so are not appropriate for low temperature applications where other types would be a better choice.
- Since they are constructed from a platinum alloy, they are quite costly and are generally reserved for extremely high temperature applications where other thermocouple types do not function well.
- Due to its high stability, type S thermocouples are used to define the International Temperature Scale between the point at which Antimony freezes (630.5 °C / 1166.9 °F) and the melting point of gold (1064.43 °C (1945.4 °F)
- Proper installation requires that the thermocouples be protected with non-metallic protection tube and ceramic insulators.
- Long term high temperature exposure causes grain growth which can lead to mechanical failure and a negative calibration drift caused by Rhodium diffusion to pure platinum leg as well as from Rhodium volatilization.
- In general type R is used in industry and type S is primarily used in the laboratory.

3.2.4.4.7 Type B

- Type B thermocouples (platinum-30% rhodium / platinum-6% rhodium) have a potential range from about 0 °C to 1820 °C (32 °F to 3308 °F).
- Type B thermocouples are commonly placed in clean air / oxidizing environments but should not be used in reduction atmospheres.
- The increased amount of Rhodium in the Type B thermocouple helps to reduce the grain growth problem allowing for a slightly increased temperature range as compared to the types R and S.

3.2.4.5 T/C Lead Wire Color Standards

Thermocouple lead wires consist of two individual wires (positive and negative), enclosed by colored insulation. Due to the Seebeck effect, thermocouple wires have a set polarity so positive and negative wires must be connected to the correct terminals. A variety of standards exist for lead wire insulation colors to identify each thermocouple type. Refer to Table 3.2.4.5a The different standards use unique wire colors to differentiate between the positive and negative leads. In North America it is typical that the negative lead is red in accordance with ASTM E230. However, the most widely used global standard for T/C wires is IEC 60584 where the negative lead is typically white. It is clear that the standard to which the T/C was manufactured must be known so that the correct color code is followed. There are other standards used in various countries including BS1843 (United Kingdom and Czech Republic), DIN43710 (Germany), JIS-C1610 (Japan), and NFC 42-324 (France). Refer to Table 3.2.4.5a.

TIP: The user must verify which standard is being used in his facility and ensure that the color codes are made available to installation, start-up and maintenance personnel.

3.2.4.6 Extension Wires

Extension wires are used to either wire thermocouples back to a control / monitoring system or to connect them to a remote transmitter. Thermocouple extension wires, with a few rare exceptions, are made of the same metal as the thermocouple wires. If the metals do not match, additional cold junctions are created at each end of the extension wire that will significantly affect the temperature measurement. In Figure 3.2.4.6a it can be seen that when copper wires are used to connect the T/C, a “premature cold junction” is created that could cause a very significant error that will vary considerably with the ambient temperature around junction 1. The measured voltage from the T/C with copper extension wires does not equal the measured voltage of the T/C with correct extension wires. In fact, if copper extension wires are used, it is nearly impossible to deduce any reasonably accurate process temperature from the measured voltage.

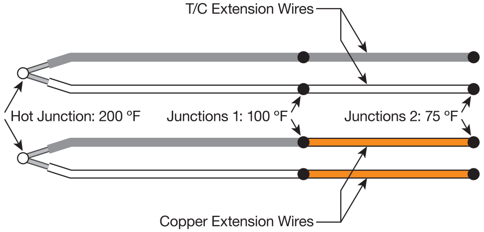


Figure 3.2.4.6a – Multiple Junctions Caused by Non-Similar Extension Wire

T/C Type	North America ASTM E230		International IEC 60584	UK BS 1843	Germany DIN 43710	Japan JIS C1610	France NFC 42-324
	Thermocouple Grade	Extension Grade					
B	n/a n/a n/a	– Conductor: Red + Conductor: Grey Sheath: Grey	– Conductor: White + Conductor: Grey Sheath: Grey	n/a n/a n/a	– Conductor: Grey + Conductor: Red Sheath: Grey	– Conductor: Grey + Conductor: Red Sheath: Grey	n/a n/a n/a
E	– Conductor: Red + Conductor: Purple Sheath: Brown	– Conductor: Red + Conductor: Purple Sheath: Purple	– Conductor: White + Conductor: Purple Sheath: Purple	– Conductor: Blue + Conductor: Brown Sheath: Brown	– Conductor: Black + Conductor: Red Sheath: Black	– Conductor: White + Conductor: Red Sheath: Purple	– Conductor: Purple + Conductor: Yellow Sheath: Purple
J	– Conductor: Red + Conductor: White Sheath: Brown	– Conductor: Red + Conductor: White Sheath: Black	– Conductor: White + Conductor: Black Sheath: Black	– Conductor: Blue + Conductor: Yellow Sheath: Black	– Conductor: Blue + Conductor: Red Sheath: Blue	– Conductor: White + Conductor: Red Sheath: Yellow	– Conductor: Black + Conductor: Yellow Sheath: Black
K	– Conductor: Red + Conductor: Yellow Sheath: Brown	– Conductor: Red + Conductor: Yellow Sheath: Yellow	– Conductor: White + Conductor: Green Sheath: Green	– Conductor: Blue + Conductor: Brown Sheath: Red	– Conductor: Green + Conductor: Red Sheath: Green	– Conductor: White + Conductor: Red Sheath: Blue	– Conductor: Purple + Conductor: Yellow Sheath: Yellow
N	– Conductor: Red + Conductor: Orange Sheath: Brown	– Conductor: Red + Conductor: Orange Sheath: Orange	– Conductor: White + Conductor: Pink Sheath: Pink	– Conductor: Blue + Conductor: Orange Sheath: Orange	n/a n/a n/a	n/a n/a n/a	n/a n/a n/a
R	n/a n/a n/a	– Conductor: Red + Conductor: Black Sheath: Green	– Conductor: White + Conductor: Orange Sheath: Orange	– Conductor: Blue + Conductor: White Sheath: Green	– Conductor: White + Conductor: Red Sheath: White	– Conductor: White + Conductor: Red Sheath: Black	– Conductor: Green + Conductor: Yellow Sheath: Green
S	n/a n/a n/a	– Conductor: Red + Conductor: Black Sheath: Green	– Conductor: White + Conductor: Orange Sheath: Orange	– Conductor: Blue + Conductor: White Sheath: Green	– Conductor: White + Conductor: Red Sheath: White	– Conductor: White + Conductor: Red Sheath: Black	– Conductor: Green + Conductor: Yellow Sheath: Green
T	– Conductor: Red + Conductor: Blue Sheath: Brown	– Conductor: Red + Conductor: Blue Sheath: Blue	– Conductor: White + Conductor: Brown Sheath: Brown	– Conductor: Blue + Conductor: White Sheath: Blue	– Conductor: Brown + Conductor: Red Sheath: Brown	– Conductor: White + Conductor: Red Sheath: Brown	– Conductor: Blue + Conductor: Yellow Sheath: Blue

Table 3.2.4.5a – International Color Coding for Thermocouple Insulation

In some cases where economic considerations may preclude the high cost of exotic metal extension wires as are the platinum alloys used in Types R, S, and B, a less expensive copper alloy that has a similar emf to that of the T/C itself may be used over a narrow range. These leads are called Compensating Leads and somewhat reduce the error described above.

Tip: There are many negative impacts on measurement performance of remote mount T/Cs including the potential errors that can be introduced into a T/C measurement by the use of extension wires or compensating leads from EMI and RFI, the costs of the specialized wire, cost of replacing T/C extension wire on a scheduled basis, and the possibility of wiring errors from color code mismatching. These considerations strongly suggest that consideration be given to using integrally mounted transmitters wherever possible.

3.2.4.7 Mounting Methods

Since T/Cs are constructed using similar sheath sizes as are RTDs, the mounting styles described above also apply to T/Cs. Refer to section 3.2.3.3 above in the RTD section.

3.2.4.8 Thermocouple Accuracy

Thermocouple accuracy is influenced by several factors including the T/C type, its range of interest, the purity of the material, electrical noise (EMI and RFI), corrosion, junction degradation, and the manufacturing process. T/Cs are available with standard grade tolerances or special grade tolerances called Class 2 and Class 1 respectively. The most common controlling international standard is IEC-60584-2. The most common U.S. standard is ASTM E230. Each standard publishes limits of tolerance for compliance. Refer to Table 3.2.4.8a and Table 3.2.4.8b.

Types	Tolerance Class 1	Tolerance Class 2	Tolerance Class 3 1)
Type T Temperature Range Tolerance Value Temperature Range Tolerance Value	 -40 °C to +125 °C ±0.5° C 125 °C to 350 °C ±0.004 · | t |	 -40 °C to +133 °C ±1 °C 133 °C to 350 °C ±0.0075 · | t |	 -67 °C to +40 °C ±1 °C -200 °C to -67 °C ±0.015 · | t |
Type E Temperature Range Tolerance Value Temperature Range Tolerance Value	 -40 °C to +375 °C ±1.5 °C 375 °C to 800 °C ±0.004 · | t |	 -40 °C to +333 °C ±2.5 °C 333 °C to 900 °C ±0.0075 · | t |	 -167 °C to +40 °C ±2.5 °C -200 °C to -167 °C ±0.015 · | t |
Type J Temperature Range Tolerance Value Temperature Range Tolerance Value	 -40 °C to +375 °C ±1.5 °C 375 °C to 750 °C ±0.004 · | t |	 -40 °C to +333 °C ±2.5 °C 333 °C to 750 °C ±0.0075 · | t |	 – – – –
Type K, Type N Temperature Range Tolerance Value Temperature Range Tolerance Value	 -40 °C to 375 °C ±1.5 °C 375 °C to 1000 °C ±0.004 · | t |	 -40 °C to +333 °C ±2.5 °C 333 °C to 1200 °C ±0.0075 · | t |	 -167 °C to +40 °C ±2.5 °C -200 °C to -167 °C ±0.015 · | t |
Type R, Type S Temperature Range Tolerance Value Temperature Range Tolerance Value	 0 °C to 1100 °C ±1 °C 1100 °C to 1600 °C ±[1 + 0,003 (t-1100)] °C	 0 °C to +600 °C ±1.5 °C 600 °C to 1600 °C ±0.0025 · | t |	 – – – –
Type B Temperature Range Tolerance Value Temperature Range Tolerance Value	 – – – –	 – – 600 °C to 1700 °C ±0.0025 · | t |	 600 °C to 800 °C +4 °C 800 °C to 1700 °C ±0.005 · | t |

1) Thermocouple materials are normally supplied to meet the manufacturing tolerances specified in the table for temperatures above -40 °C. These materials, however, may not fall within the manufacturing tolerances for low temperatures given under Class 3 for Types T, E, K and N. If thermocouples are required to meet limits of Class 3, as well as those of Class 1 or 2, the purchaser shall state this, as selection of materials is usually required.

Table 3.2.4.8a – Thermocouple Tolerance Requirements for Compliance with IEC 60584-2

Tolerances on Initial Values of Emf vs. Temperature for Thermocouples

NOTE 1 – Tolerances in this table apply to new essentially homogeneous thermocouple wire, normally in the size range 0.25 to 3mm in diameter (No. 30 to No. 8 AWG) and used at temperature not exceeding the recommended limits of Table 6 (?). If used at higher temperatures these tolerances may not apply.

NOTE 2 – At a given temperature that is expressed in ˚C, the tolerance expressed in ˚F is 1.8 times larger than the tolerance expressed in ˚C. Where tolerances are given in percent, the percentage applies to the temperature being measured when expressed in degrees Celsius. To determine the tolerance in degrees Fahrenheit, multiply the tolerance in degrees Celsius by 9/5.

NOTE 3 – **Caution:** Users should be aware that certain characteristics of thermocouple materials, including the Emf-vs.-temperature relationship may change with time in use; consequently, test results and performance obtained at the time of manufacture may not necessarily apply throughout an extended period of use. Tolerances given in this table apply only to new wire as delivered to the user *and do not allow for changes in the characteristics with use.* The magnitude of such changes will depend on such factors as wire size, temperature, time of exposure, and environment. It should be further noted that due to possible changes in homogeneity, attempting to recalibrate *used* thermocouples is likely to yield irrelevant results, and is not recommended. However, it may be appropriate to compare used thermocouple *in-situ* with new or known good ones to ascertain their suitability for further service under the conditions of the comparison.

Thermocouple Type	Temperature Range		Tolerances-Reference Junction 0 °C [32 °F]			
			Standard Tolerances		Special Tolerances	
	°C	°F	**°C** (whichever is greater)	°F	**°C** (whichever is greater)	°F
T	0 to 370	32 to 700	±1.0 or ±0.75%	Note 2	±0.5 or ±0.4%	Note 2
J	0 to 760	32 to 1400	±2.2 or ±0.75%		±1.1 or ±0.4%	
***E**	0 to 870	32 to 1600	±1.7 or ±0.5%		±.01 °C or ±0.4%	
K or N	0 to 1260	32 to 2300	±2.2 °C or ±0.75%		±1.1 °C or ±0.4%	
R or S	0 to 1480	32 to 2700	±1.5 °C or ±0.25%		±0.6 °C or ±0.1%	
B	870 to 1700	1600 to 3100	±0.5%		±0.25%	
C	0 to 2315	32 to 4200	±4.4 or 1%	Note 2	Note applicable	
T[A]	-200 to 0	-328 to 32	±1.0 or ±1.5%		[B]	
***E**[A]	-200 to 0	-328 to 32	±1.7 or ±1%		[B]	
K[A]	-200 to 0	-328 to 32	±2.2 or ±2%		[B]	

* The standard tolerances shown do not apply to **Type E** mineral-insulated, metal-sheathed (MIMS) thermocouples and thermocouple cables as described in Specifications E608/E608M and E585/E585M. The standard tolerances for **MIMS Type E** constructions are greater of ±2.2 ˚C or ±0.75% from 0 to 870 ˚C and the greater of ±2.2 ˚C or ±2% from -200 to 0 ˚C.

[A] Thermocouples and thermocouple materials are normally supplied to meet the tolerances specified in the table for temperatures above 0 ˚C. The same materials, however, may not fall within the tolerances for temperature below 0 ˚C in the second section of the table. If materials are required to meet the tolerances stated for temperatures below 0˚ C the purchase order shall so state. Selection of materials usually will be required.

[B] Special tolerances for temperatures below 0 ˚C are difficult to justify due to limited available information. However, the following values for **Types E** and **T** thermocouples are suggested as a guide for discussion between the purchaser and supplier:

Type E, -200 to 0 ˚C, ±1.0 ˚C or ±0.5% (whichever is greater)
Type T, -200 to 0 ˚C, ±0.5 ˚C or ±0.8% (whichever is greater)

Initial values of tolerance for **Type J** thermocouples at temperatures below 0 ˚C and special tolerances for **Type K** thermocouples below 0 ˚C are not given due to the characteristics of the materials. Data for **Type N** thermocouples below 0 ˚C are not currently available.

Table 3.2.4.8b – Thermocouple Tolerance Requirements for Compliance with ASTM E230 -11

3.2.5 Measurement Response Time Considerations

A sensor's dynamic response time can be important when the temperature of a process is changing rapidly and fast inputs to the control system are needed. A sensor installed directly into the process will have a faster response time than a sensor with a thermowell.

It's important to note that when no thermowell is used, the sensing element is exposed to the process and cannot be replaced without interrupting the flow which often requires a process shutdown and draining the process system. Engineering guidelines in most process facilities will not permit exposed sensors. Such installations are far less safe against potential loss of containment of process fluids, can cause more frequent sensor failure from exposure to adverse process conditions, and often require an expensive process shutdown to change out a failed sensor. Use of a thermowell is the solution to this problem.

However, when a thermowell is used, response time clearly increases due to the increased thermal mass of the assembly. The key to optimizing response time is to reduce the mass while maintaining adequate physical strength to withstand the process pressures and flow forces. Smaller diameter thermowells provide faster response, since less material needs to be heated or cooled. A properly fit sensor is also important to achieve a faster response time. The sensor needs to be long enough so its tip is touching the bottom of the thermowell bore for good conduction. The sensor diameter also needs to fit snugly into the thermowell bore so there is a minimum air gap between the sensor and the thermowell. Additionally, response time is improved by using a spring-loaded sensor and filling the voids in the well with thermally conductive fluid. The characteristics of the medium being measured are also factors, especially with regard to flow velocity and density. A fast moving medium transfers heat and changing temperature better than a slow moving one, and higher density media (fluids) are better heat conductors than lower density media (gases). (Refer to Thermowell chapter 3.3 for more detail.)

When comparing the response of temperature measurement systems using an bare T/C or an bare RTD in a flowing water application, it has shown that a grounded tip T/C will respond about 2 times faster than will a spring-loaded RTD sensor. For measurements in flowing air an RTD is slightly faster than a T/C.

However, that advantage is greatly minimized, if not eliminated, when the sensor is installed in a thermowell. The mass of a thermowell is so large as compared to the mass of a sensor, that it clearly dominates the response characteristics of the system.

When using a 6mm (1/4") diameter sensor in a water measurement application, T/C and RTD response is about the same and when using a 3mm diameter sensor a T/C is slightly faster than an RTD. For measurements in air the response is about the same for both RTDs and T/Cs using either a 3mm (1/8") or 6mm sensor.

Tip: Since very few process applications use bare sensors for measurement, the inherent speed advantage of a T/C is greatly reduced and possibly eliminated for most applications. The wise engineer will select the best sensor for the application based on a myriad of other factors and not be influenced by the misleading statements made so often that "T/Cs are always faster than RTDs".

3.2.6 Multipoint and Profiling Sensors

Multipoint Temperature Profiling Sensors measure temperatures at different points along their length. They have found frequent use in the chemical and petrochemical industries to provide temperature profiles for tanks, reactors, catalytic crackers and fractionation distillation towers or columns. Multipoint Temperature Profiling Sensors provide a cost-effective, easily installed and maintained data acquisition solution.

These profiling sensors can provide from 2 to 60+ measurement points within a single protection tube using a single penetration. The sensors can be either RTDs or T/Cs depending on the requirements of the application. Refer to vendor product data sheets for complete details and refer to Chapter 9 for some application examples.

Summary

In this chapter we have provided a detailed insight into the theory, design, construction, installation and operation of the two primarily used temperature sensors in the industrial process industries, RTDs and Thermocouples. From the discussion of each of these sensor's performance and accuracy capabilities, it may be deduced that there are many decision factors involved in choosing the correct sensor for your application. For some high temperature applications T/Cs are the only choice and for other applications either sensor would function. The decision of choice lies with other considerations including required measurement system accuracy, long term performance and cost of ownership.

These topics and many more are presented in further detail in Chapter 4.2.

3.3 Thermowells

3.3.1 Overview

Temperature sensors are rarely inserted directly into an industrial process. They are installed into a thermowell to isolate them from the potentially damaging process conditions of flow-induced stresses, high pressure, and corrosive chemical effects. Thermowells are closed-end metal tubes that are installed into the process vessel or piping and become a pressure-tight integral part of the process vessel or pipe. They permit the sensor to be quickly and easily removed from the process for calibration or replacement without requiring a process shutdown and possible drainage of the pipe or vessel.

The most common types of thermowells are threaded, socket weld, and flanged. Thermowells are classified according to their connection to a process. For example, a threaded thermowell is screwed into the process; a socket weld thermowell is welded into a weldalet and a weld-in thermowell is welded directly into the process pipe or vessel. A flanged thermowell has a flange collar which is attached to a mating flange on the process vessel or pipe.

3.3.2 Thermowell Types

Thermowells are most often constructed from machined barstock in a variety of materials and may be coated with other materials for erosive or corrosive protection. They are available with threaded, welded or flanged connections. The stem or shank that extends into the process may be straight with constant diameter, tapered all the way from entry point to the tip, partially tapered, or stepped. See Figure 3.3.2a.

A variety of performance criteria and process conditions must be considered when selecting the best design for an application. In the following sections we will discuss detailed aspects of thermowell design and their application.

Figure 3.3.2a – Thermowell Family

3.3.3 Thermowell Design Insights

3.3.3.1 Materials

The material of construction is typically the first consideration in choosing a thermowell for any given application. Three factors affect the choice of material:

- Chemical compatibility with the process media to which the thermowell will be exposed
- Temperature limits of the material
- Compatibility with the process piping material to ensure solid, non-corroding welds and junctions

It is important that the thermowell conform to the design specs of the pipe or vessel into which it will be inserted to ensure structural and material compatibility. The original design of the process had most likely included temperature, pressure and corrosive considerations as well as cleaning procedures, agency approvals required and conformance with codes or standards. Since an installed thermowell effectively becomes part of the process, these original design considerations also apply to the thermowell and will drive the thermowell material of construction and mounting type selection. International pressure vessel codes are explicit about the types of materials and the methods of construction allowed. Although there is no equivalent to the pressure vessel codes for thermowells, the ASME BPVC and B31 standards do have considerations for the different types of pipe fittings including flanged, socket-welded and threaded. Details on these considerations can be found in the following:

ASME B16.5 covers flanged fittings; ASME B16.11 covers socket-welded and threaded fittings. Also for reference, the ASME B31.3 covers process piping while ASME B31.1 covers power piping, and ASME B40.9 covers thermowells specifically (although in a more general sense). Due consideration should be

Figure 3.3.3.1a - Thermowell Installation Examples

given to these codes when specifying thermowells as integral parts of the process structure

Errors in the specification of pressure retaining components could have disastrous results leading to loss of life, loss of containment and even potential prosecution. See Thermowell Installation Examples Figure 3.3.3.1a.

Although there are many choices of thermowell material of construction, the most commonly used materials are 316 stainless steel, 304 stainless steel, Monel®, Inconel®, and Hastelloy®. See Figure 3.3.3.1b. There are also some exotic metals for very demanding applications.

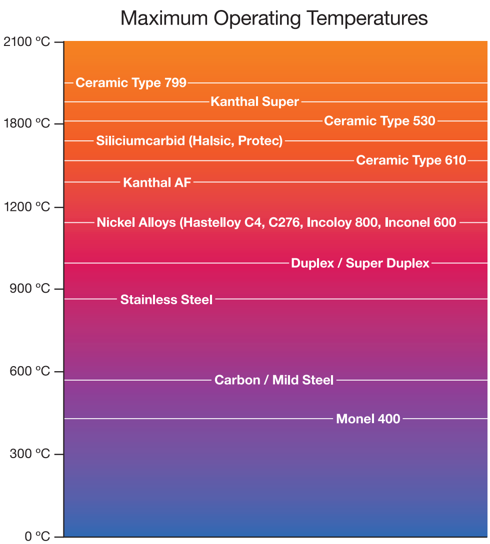


Figure 3.3.3.1b – Thermowell Material Recommendations

3.3.3.2 Styles

Thermowells are generally either tubular or machined from barstock. Each style has pros and cons and selection of the proper thermowell depends on the requirements of the application.

3.3.3.2.1 – Protection tubes, sometimes called Tubular Thermowells, are fashioned by welding a flange or threaded fitting to one end of tube or small section of pipe or tubing and capping the other end. Protection tubes can also be constructed of ceramic material and bonded to a metal process fitting. Tubular thermowells can be constructed for very long immersion lengths and are often used for measurements where flow forces are low. Since they are fabricated from tubing, they have a much larger bore than other thermowells which causes a considerable thermal lag. See Figure 3.2.3.8b.

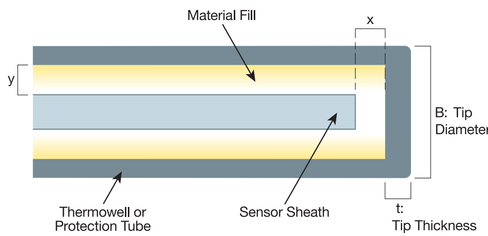


Figure 3.2.3.8b – Factors Affecting Response Time for a Large Bore Thermowell

Due to their construction, they have a much lower pressure rating and the choice of materials is limited. For measuring temperatures up to 1800 °C the protection tubes are made from a ceramic material. For temperatures up to about 1200 °C they are often made from exotic metals like Inconel. Ceramics are not prone to sagging as are metal tubes. When metal tubes sag it is more difficult, if not impossible, to remove a sensor for replacement and the bending can damage the sensor. Refer to Figure 3.3.3.2.1a and Figure 3.3.3.2.1b.

Figure 3.3.3.2.1a – High Temperature Thermowell Assembly

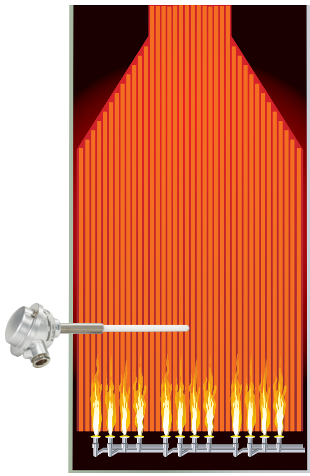


Figure 3.3.3.2.1b – Typical High Temperature Installation

3.3.3.2.2 - Barstock thermowells are machined from a solid piece of round or hex shaped metal. Barstock thermowells can withstand higher pressures and faster flow rates than protection tubes. They have more material options and can be mounted in various ways to meet different process pressure requirements. Lengths are typically limited due to bore drilling limitations. See Figure 3.3.2a in section 3.3.2.

3.3.3.3 Stem Profiles

Factors to be considered when selecting a stem style include the process pressure, the required speed of response of the measurement, the drag force of the fluid flow on the well and the vortex shedding induced vibration effects.

The stem or shank is the part of a thermowell that is inserted into the process piping. The common stem profiles are straight, stepped, and tapered. See Figure 3.3.3.3a.

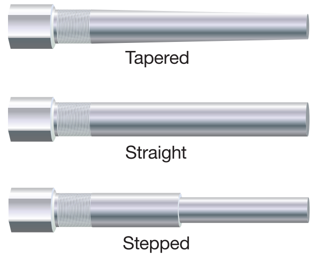


Figure 3.3.3.3a – Thermowell stem profiles

3.3.3.3.1 – Straight profile thermowells have the same diameter along the entire immersion length. They present the largest profile to the process medium and therefore have the highest drag force as compared to other well styles with the same root diameter. Because of the large tip diameter there is more mass to heat which slows the thermal response of the measurement assembly. See Figure 3.3.3.3.1a.

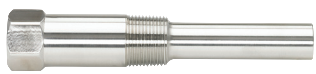


Figure 3.3.3.3.1a – Straight Profile Thermowell

3.3.3.3.2 – Stepped profile thermowells have two straight sections with the smaller diameter straight section at the tip. Refer to Figure 3.3.3.3.2a. For the same root diameter as a straight profile thermowell, this design has less profile exposure to the flowing process and therefore exhibits less drag force and quicker response time due to the smaller mass at the tip. In general, stepped thermowells will have thinner walls. By the geometry of its design, the stepped well has a higher natural frequency than the other profile designs of the same root diameter and is therefore less susceptible to vibration induced failure. See Vibration section 3.3.7 below for more detail.

Figure 3.3.3.3.2a – Stepped Thermowell

3.3.3.3.3 – Tapered profile thermowells have an outside diameter that decreases uniformly from root to tip. For the same root diameter, this profile represents a good compromise between straight and stepped thermowells. It's drag will be less than a straight type well but greater than a stepped type well. Also the response time will be faster than a straight type and slower than a stepped type. The two general forms of a tapered stem are uniform (tapered from root to tip) and non-uniform (straight portion followed by tapered portion). See Figure 3.3.3.3.3a. Because of its profile shape it is a good compromise for strength between the two other styles. It is the common choice for high velocity flow applications where the flow forces typically are too great to use a stepped well and the tapered design has faster response than the straight type thus offering an optimal balance of strength and response factors.

Figure 3.3.3.3.3a – Tapered Threaded and Tapered Flanged Thermowells

3.3.4 Mounting Methods

Thermowells are typically mounted by one of the following methods: See Figure 3.3.4a.

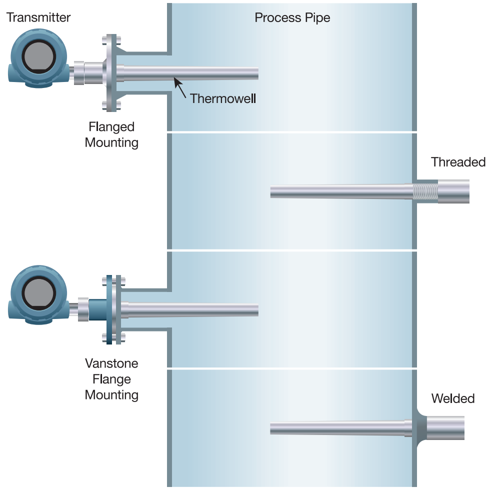


Figure 3.3.4a – Thermowell Mounting Methods

3.3.4.1 – Threaded thermowells are threaded into process piping or tank, which allows for easy installation and removal when necessary. While this is the most commonly used method of mounting, it has the lowest pressure rating of the three options. Threaded connections are also prone to leakage and therefore are not recommended for applications with toxic, explosive or corrosive materials.

3.3.4.2 – Welded thermowells are permanently welded to process pipes or tanks. Thus, removal is difficult and requires cutting the thermowell out of the system. Welded thermowells have the highest pressure rating and are generally used in applications with high velocity flow, high temperature, or extreme high pressure. They are necessary where a leak-proof seal is required.

3.3.4.3 – Flanged thermowells are bolted to a mating flange that is welded onto process pipe or tank. They provide high pressure ratings, easy installation, and simple replacement. Flanged thermowells are used in applications with corrosive environments, high-velocity, high temperature, or high pressure.

3.3.4.4 – Vanstone / Lap Joint thermowells are mounted between the mating flange and the lap joint flange. These thermowells allow for the use of different materials for the thermowell coming in contact with the process and the overlaying flange which can save material and manufacturing costs. They are a good choice for corrosive applications since there are no welds in this design weld-joint corrosion is eliminated. As an option they can be provided as a forging.

3.3.5 Mounting Options

To accommodate pipe or vessel insulation layer thickness or other offset considerations like high ambient temperature, a thermowell may be specified with varying lagging lengths. See Figure 3.3.5a and the "Selecting and Installing" section 4.2 for more detail.

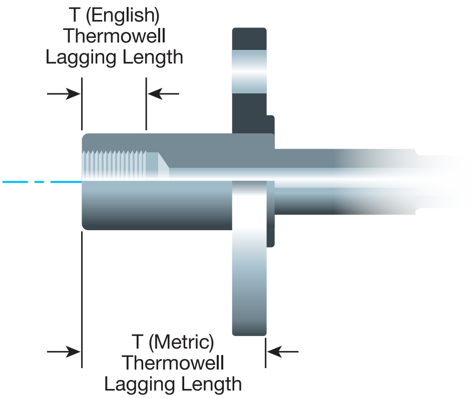


Figure 3.3.5a – Thermowell Lagging Length

3.3.5.1 Installation without a Thermowell

In the industrial process industry thermowells are used for almost all applications. Some examples of exceptions to that rule include applications for very-low-pressure air or ventilating systems, bearing temperature measurement, and lube oil drain in compressors. Reasons for direct immersion are usually associated with a requirement for faster response or where there are space limitations such as casing drain in compressors. Installing temperature elements without a thermowell is acceptable in some applications or where certain conditions exist:

- The process fluid is not corrosive or otherwise hazardous
- The process is not under significant pressure
- Air-in leakage is permissible
- The primary element has the necessary static and dynamic mechanical strength for the application
- A failure of the element may be tolerated until the process can conveniently be shut down and assuming the operation can continue without the use of the measurement
- There is no personnel hazard if the temperature sensor is inadvertently removed from the vessel, pipe or duct.

3.3.6 Manufacturing

Thermowells are machined on special-purpose high-accuracy machines exercising careful quality control to ensure concentricity of the bore with respect to the outside diameter and a consistent wall-thickness over the full length of the thermowell. Meeting these criteria is essential to ensure that the thermowell meets the stated pressure ratings that are related to uniform wall thickness. This in turn relates to code conformance as was described above.

3.3.7 Thermowell Failure Considerations

Thermowell failures are often associated with one or more of the following: high drag forces, excessive static pressure, high temperature, corrosion and fluid induced vibration.

3.3.7.1 Vibration

Most thermowell failures are caused by fluid induced vibration. See Figure 3.3.7.1a.

When fluid flows past a thermowell inserted into a pipe or duct, vortices form at both sides of the well. These vortices detach, first from one side, and then from the other in an alternating pattern. This phenomenon is known as vortex shedding, the Von Karman Vortex Street or flow vortices. The differential pressure due to the alternating vortices produces alternating forces on the well resulting in stresses that cause alternating transverse deflection. In addition there are other forces produced along the axial or parallel axis of the flow. See Figure 3.3.7.1b. The frequency of shedding of these vortices – called the vortex shedding frequency (or fs) – is a function of the diameter of the thermowell, the fluid velocity and, to a lesser extent, the Reynolds number.

Figure 3.3.7.1a – Example of a Thermowell Failure

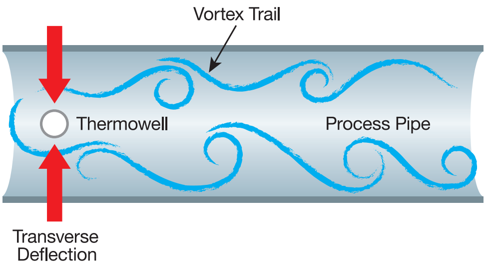


Figure 3.3.7.1b – The von Karman Trail, Showing Transverse Force Deflection and Direction

Each thermowell design has a natural frequency referred to as fn that is dependent on its shape, length, and material of construction.

As the vortex shedding frequency approaches the natural frequency of the thermowell, the thermowell will oscillate in resonance and may fracture with potentially dire consequences.

It is clear that the vortex shedding forces must be taken into account when selecting a thermowell of sufficient strength and stiffness to withstand the service conditions, and generally thermowells are selected such that the shedding frequency is always ≤ 80% of the natural frequency. Or mathematically as a ratio, where fs÷ fn ≤ 0.8. For liquid flow with a fs÷ fn ratio from 0.4 to 0.5, the axial forces are an important factor of concern.

By the geometry of its design, the stepped well has a higher natural frequency than the straight or tapered profile designs with the same root diameter and will typically produce a wider separation of the vortex shedding wake frequency fs from the natural frequency of the thermowell fn (Lower ratio) resulting in less chance of resonant oscillation leading to potential thermowell failure.

Tip: Wake frequency is a determining factor in selecting a thermowell for a high-velocity application. Most manufacturers have a software tool to provide an analysis of the wake frequency effects that predicts probability of failure of the thermowell. This tool is a great help for the proper choice of thermowell to meet the application requirements. These tools are defined in ASME PTC 19.3 TW-2010.

Tip: The long awaited PTC 19.3 TW-2010 is a completely new standard that establishes the practical design considerations for thermowell installations in power and process piping. This code is an expanded version of the thermowell section contained in the PTC 19.3-1974, and incorporates the latest theory in the areas of natural frequency, Strouhal frequency, in-line resonance and stress evaluation. It includes

- Expanded coverage for thermowell geometry
- Natural frequency correction factors for mounting compliance, added fluid mass, and sensor mass
- Consideration for partial shielding from flow
- Intrinsic thermowell damping
- Steady state and dynamic stress evaluations
- Improved allowable fatigue limit definition.

See Reference Material in Chapter 8 for a white paper “Thermowell Calculations” detailing insights into the provisions and requirements of PTC 19.3 TW-2010.

3.3.8 Response Time Considerations

As was discussed in the Sensors chapter, the speed of response of the sensor itself is dwarfed by the much slower response of the measurement system using a thermowell. The mass of the thermowell far exceeds that of the sensor and will always be the dominant factor of measurement response.

Several factors affect the overall response time of temperature measurements when thermowells are used, including:

- Stem style
- Tip thickness and diameter
- Sensor sheath OD to thermowell bore ID gap. (“y” dimension in Figure 3.2.3.8b)
- A Thermally conductive fill material such as Silicone oil will provide far faster response than will an air gap
- Process media (liquid, steam or vapor) See Table 3.3.8a – The more dense the fluid, the faster the response
- Process flow rate with faster rates providing shorter response time

For systems where the fastest possible response is needed, there are system design considerations that will optimize measurement speed including: Refer to Figure 3.3.8a.

Thermal Time Response Data (per IEC 751)
Sensor and Thermowell in water flowing at 0.4 meters/sec

1067 Sensor - 6mm diameter											
1097 (D22) Thermowell		Pt 100			Pt 100			Pt 100			
Material	Material Code	t(0.5) [s]	t(0.63) [s]	t(0.9) [s]	t(0.5) [s]	t(0.63) [s]	t(0.9) [s]	t(0.5) [s]	t(0.63) [s]	t(0.9) [s]	Deviation
316L Stainless steel	A2	29	37	75	26	37	85	29	40	89	± 10%
304L Stainless steel	A5	29	37	75	26	37	85	29	40	89	± 10%
304L Stainless steel with carbon steel flange	A6	29	37	75	26	37	85	29	40	89	± 10%
316L Stainless steel with Tantalum sheath	B2	75	96	183	67	88	184	64	85	180	± 10%
316L Stainless steel with Tantalum sheath with Platinum beads	B3	75	96	183	67	88	184	64	85	180	± 10%
316L Stainless steel with PFA coating	B4	76	97	181	78	101	197	80	104	203	± 10%
Carbon Steel	C1	29	37	75	26	37	85	29	40	89	± 10%
Alloy 20	D1	27	35	71	34	46	98	31	41	90	± 10%

Table 3.3.8a – Excerpt from Response Data Test Report

- Select a stepped well which has less mass at the tip than do the straight and tapered thermowells. (Dimensions “B” and “t”) (Straight wells are the slowest and tapered are a compromise between the two.)
- Use a tip sensitive sensor so that the sensitive portion is at the thinnest part of the well.
- Select a spring loaded sensor to ensure tight contact of the sensor to the bottom of the well. (“x” = 0 in Figure 3.2.3.8b)
- Specify a thermally conductive media to fill the void between the sensor and the wall of the thermowell. (“y” dimension in Figure 3.2.3.8b)
- Specify the proper immersion length to ensure that the tip of the well is in the faster moving part of the fluid flow stream. (The faster the flow the faster will be the response for a given fluid density.)

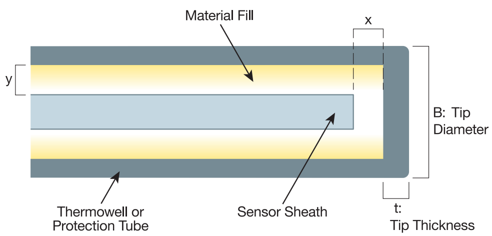


Figure 3.2.3.8b – Factors Affecting Response Time

3.3.9 Thermowell Standards

3.3.9.1 – The ASME PTC 19.3TW-2010 is internationally recognized as a mechanical design standard yielding reliable thermowell service in a wide range of temperature measurement applications. It includes evaluation of stresses applied to a barstock thermowell as installed in a process based on the design, material, mounting method, and the process conditions. For detailed information about this standard refer to the white paper “Thermowell Calculations” in Chapter 8, Reference Materials.

3.3.9.2 – The Energy Institute Section T.4, Guidelines for Avoidance of Vibration Induced Fatigue Failure in Process Pipework, provides an overview of vibration characteristics and how vibration affects piping systems. This is a useful document on the handling of vibration with some information that is specific to thermowells. Included is a quantitative assessment to determine the “likelihood of failure” (LOF) using a natural frequency calculation based on wall thickness. This document also presents valid information on corrective actions that can be taken to ensure longevity of existing thermowells.

3.3.9.3 – DIN 43772 is a European (German) standard with specifications for thermowell design, construction, and materials. The design specifications cover various types of thermowells, dimensions, wall thicknesses, types of construction, connection methods, and requirements for marking and testing thermowells and extension tubes. Also included are limited strength evaluations (load diagrams) based on flow conditions.

3.3.9.4 – ASME B16.5 standard controls the design of pipe flanges and flanged fittings. Included are pressure/temperature ratings for various fitting methods and materials of construction and complete dimensional specifications and tolerances. Pressure testing is also covered.

Summary

As has been discussed in this chapter, there are many considerations involved in selecting a proper thermowell for your temperature measurement system. The system design engineer must gather all available process information and performance expectations before beginning the system design. Front end engineering will pay large dividends by providing an optimally performing temperature measurement system with the lowest cost of ownership.

4

Engineering and Design

TOPIC PAGE

4.1 Understanding Your Temperature Measurement System

4.1.1 Overview

Temperature is a critical factor in many industrial processes including reaction, fermentation, combustion, drying, calcinations, drying, crystallization, and extrusion.

If a temperature measurement is not accurate or reliable for any reason, it could have a detrimental effect on process efficiency, energy consumption, product quality and possibly process safety. As an example; for incinerators, there is an optimum temperature control point to ensure complete destruction of hazardous compounds while maintaining minimum energy cost. Even a small measurement error can be disruptive in some processes, so it's extremely important to be certain your temperature measurements are accurate and reliable. There are other processes however where temperature is only monitored for trends and absolute accuracy and stability are not important factors. For this reason, each measurement system needs to be evaluated and carefully engineered to satisfy the specific process requirements.

Obtaining the correct sensor, installing it properly, and conveying a temperature measurement signal to a control or monitoring system requires much more analysis than just selecting a thermocouple or RTD out of a catalog. Selecting the best transmitters for the application and how they should be mounted is equally important. Thorough investigations to understand the temperature measurement system requirements will pay off in providing a cost-effective installation that meets those requirements of measurement accuracy, response time, and signal reliability.

Even though it is such a common process variable, temperature is one that is the most misunderstood as to how to make a reliable measurement. These misunderstandings fool many users into believing that they are making a better measurement than they are in reality. When determining measurement precision, accuracy and drift characteristics must be considered for both the sensor and the transmitter. Environmental conditions at the measurement site can also have a significant impact on the measurement performance.

The basic question is: What is the best way to relate sensor and transmitter performance considerations to real world temperature measurement systems?

While the sophistication of electronics has improved dramatically over the years, the basic fact that measurement is only as good as its weakest link has (and will) endure forever. The sensor is almost always the weakest link in modern temperature systems. And while I/O subsystems (DCS or PLC input cards) have reasonable specifications, they are no match for the performance of today's quality temperature transmitters.

Most still get confused on when to use a Resistance Temperature Detector (RTD) vs. using a Thermocouple (T/C). The cost/performance trade-offs of using transmitters vs. direct wiring to a receiver are also widely misunderstood.

For Safety Instrumented Systems (SIS), the guidance provided by the standards suggests a thorough understanding of the reliability aspects of making a stable and dependable measurement.

4.1.2 Selection Criteria

To the new or inexperienced engineer it may seem like a daunting task to select the proper temperature measurement system for an application. To properly design a reliable temperature measurement system for each application, a series of questions need to be answered to thoroughly understand the application such that the best choice of components of the system is made including the thermowell, the sensor, and the signal conditioning device. Performance requirements of the measurement must also be determined. Operating conditions during startup, steady-state, and potential abnormal conditions must all be considered. Some applications require the utmost in precision while others are merely monitoring trends such that the component selection could be quite different.

To select a proper thermowell the process conditions must be identified, as they will influence decisions regarding the material of construction, the well design, the insertion length and the lagging required. The performance expectations will drive selection of the sensor and the signal conditioning device.

As with any task, a logical and methodical approach usually begins with understanding the performance and physical requirements of the measurement application that will usually lead to the best path to follow for a well engineered solution.

Review of process P&IDs, a site visit to ensure that the drawings are accurate and to visualize the mounting location, and consultation with process, mechanical, environmental engineers and project managers will usually provide answers to such questions as:

- What is the process?
- What is the process fluid? (Gas, liquid, steam or granular)
- What is the operating pressure? The maximum pressure?
- What is the normal, maximum and minimum fluid flow rate?
- Is the measurement in a pipe or a vessel?
- Is the pipe or vessel full or partially filled?
- What is the ambient temperature range around the measurement point?
- Where will the measurement be taken? Ground level or elevated?
- Is it desirable to have the field operator view a local display?
- Is the requirement to monitor temperature trends or an actual controlled value?
- What is the temperature range? The control point? Its maximum temperature? Its minimum temperature?
- Are there established plant preferences for choice of sensor that may influence your selection? (Proven in use is a valuable consideration)
- What is the control precision requirement? For example furnace temperature control may tolerate ± 10 °C while a pharmaceutical batch process may require ± 0.25 °C or better.
- What is the speed of response to temperature change requirement?
- Is there a significant ROI for best possible accuracy and stability? (Like custody transfer, energy management or distillation column throughput for example)
- What are the costs associated with a measurement failure? Production downtime costs? Off-spec product that requires reprocessing or selling at a reduced price? Energy inefficiency? Troubleshooting and maintenance time? Dangerous runaway reactions?
- What are the plant engineering standards for installation? Integrally mounted transmitters; remote-mount transmitters; direct wiring to marshalling cabinets; etc.)
- What other corporate or plant level guidance policies and procedures must be observed
- What are the physical parameters? Pipe material, insulation thickness and diameter; tank material, wall and insulation thickness; reactor detail; duct detail; etc.
- Are there any obstructions in the intended mounting location?
- Are there explosive, abrasive or corrosive considerations in the process? In the surrounding environment?
- What is the frequency and severity of the piping / vessel vibration (typical and maximum?)
- How fast will the temperature change during normal operation? During an upset condition?
- Is there the expectation of significant EMI, electrical surges, and RFI in the area of the measurement from pumps, motors, radio antennas, welders, etc.?
- Is this measurement part of a safety instrumented system?

After gathering answers to the above questions, there should be adequate information to make informed decisions about the choice of thermowell, sensor and signal conditioning device.

4.1.3 Installation Best Practices

Following is guidance on best practices for a reliable installation.

- Have a thorough understanding of the requirements of the application
- Whenever possible visit the site and talk to those who know the process and the applicable codes,

standards and plant practices for that facility and ensure that your design and specifications are in compliance

- Typically total wire length between the measurement point and the control system is between 2 to 3 times longer than the line of sight distance due to positioning of conduits and wireways.
- Always consider cost of ownership not purchase cost in your design. Poor performance, more frequent replacement and higher maintenance costs associated with low cost products or deficient designs most often tilt the cost of ownership scale in favor of a proper design using high quality components
- Always allow for a margin of error in your design performance. A rule of thumb is 4 times better accuracy than what is specified by the process engineers
- For many applications a properly specified RTD sensor should be the first choice unless the temperature range exceeds 600 °C. Up to 850 °C the choice is application driven and over 850 °C a T/C is the only practical choice.
- Many applications in the refining and metal processing industries typically use T/C sensors
- Consider specifying and using transmitter intelligent filtering, diagnostics and other options to enhance measurement integrity, reliability and accuracy. Refer to Transmitter Chapter, Section 6.
- For non fieldbus systems, make use of the HART capabilities for configuration, maintenance and enhanced monitoring of transmitter operation and performance
- For applications where high measurement precision provides a significant process performance benefit, strongly consider sensor-transmitter matching. Examples include temperature compensation for custody transfer of gasses, energy management, and distillation column throughput.
- Proper grounding, shielding and surge protection can pay huge dividends in enhanced system performance
- For SIS applications there are many guidelines and procedures that must be followed to be in compliance with the safety standards. These include use of properly certified transmitters, use of specified redundancy strategies, commissioning, proof testing and documentation.
- For high velocity or high viscosity applications a failure probability analysis should be performed on the thermowell design to ensure selecting a design that will withstand the vibration stress caused by vortex shedding forces. See Thermowell Chapter, Section 3.3.

HOW TO CHOOSE THE CORRECT THERMOWELL

Temperature sensors are rarely inserted directly into an industrial process. They are installed into a thermowell to isolate them from the potentially damaging process conditions of flow-induced stresses, high pressure, and corrosive chemical effects. Thermowells are closed-end metal tubes that are installed into the process vessel or piping and become a pressure-tight integral part of the process vessel or pipe.

To select a proper thermowell the process conditions must be identified, as they will influence decisions regarding the material of construction, the well design, the insertion length and the lagging required.

Refer to:

4.1.2 – Selection Criteria

4.2.2 – Thermowell Overview

3.3.7 – Thermowell Failure Considerations

4.2 Selecting and Installing the Correct Components

4.2.1 Overview

In this section we will discuss the selection of the proper Thermowell, Sensor, and Signal Conditioning Device to best meet the physical and performance requirements of your temperature measurement system. As you proceed through this section keep in mind the concept of cost of ownership. It is often foolish to "buy cheap" to meet a budget and then find out later that such things as poor performance, higher maintenance costs or more frequent replacement are costing the facility many times over the original savings.

Tip: Before proceeding in this section it will be assumed that you have read the "Understanding Your Temperature Measurement System" Section 4.1 of this Engineering Chapter and have gathered the required process information by obtaining answers to the questions provided.

4.2.2 Thermowell Overview

Temperature sensors are rarely inserted directly into an industrial process. They are installed into a thermowell to isolate them from the potentially damaging process conditions of flow-induced stresses, high pressure, and corrosive chemical effects. Thermowells are closed-end metal tubes that are installed into the process vessel or piping and become a pressure-tight integral part of the process vessel or pipe. They permit the sensor to be quickly and easily removed from the process for calibration or replacement without requiring a process shutdown and drainage of the pipe or vessel.

TIP: Refer to the "Thermowells" Section 3.3 in the Temperature Measurement Basics, Chapter 3 for additional thermowell information.

Thermowells are most often constructed from machined barstock in a variety of materials and may be coated with other materials for erosive or corrosive protection. Thermowells are classified according to their connection to a process. For example, a threaded thermowell is screwed into the process; a socket weld thermowell is welded into a weldalet and a weld-in thermowell is welded directly into the process pipe or vessel; a flanged thermowell has a flange collar which is attached to a mating flange on the process vessel or pipe. The stem or shank that extends into the process may be straight with constant diameter, tapered all the way from entry point to the tip, partially tapered, or stepped. They are available with threaded, welded or flanged connections. Also See Figure 3.3.2a.

Figure 3.3.2a – Typical Thermowell Styles

4.2.2.2 Installing a New Thermowell

4.2.2.2.1 Locate the Point of Penetration

Start by locating a suitable measurement point that is representative of the desired measurement and is accessible. Determine the size of the pipe or vessel, the insulation thickness, and the presence of surrounding structures that may impede installation of the thermowell and future maintenance or replacement access. Take into consideration the dimension of the entire assembly including an integrally mounted transmitter or connection head.

For installations downstream of static mixers or heat exchangers the insertion point must optimize the tradeoffs of minimal thermal loss with adequate mixing to avoid two phase flow or process noise. Generally a downstream distance of about 25 pipe diameters is sufficient. There are special considerations for some other difficult applications like desuperheaters where stream velocity conditions must be considered. After a suitable location is chosen, determine if it will be necessary to drain and clean the pipe or vessel before cutting into it to install the well. Ensure that the appropriate permits and approvals are secured.

4.2.2.2.2 Select Material of Construction

The material of construction is typically the first consideration in choosing a thermowell for any given application. Factors that affect the choice of material include:

- Chemical compatibility with the process media
- Temperature limits of the material Figure 3.3.3.1b
- Compatibility with the process piping or vessel material to ensure solid, non-corroding welds and junctions Figure 4.2.2.2.2a

It is important that the thermowell conform to the design specs of the pipe or vessel into which it will be inserted to ensure structural and material compatibility.

Materials	Recommended Usage	Process Rating(1) (psi) at Temperature (°F)						
		0 °F	300 °F	500 °F	700 °F	900 °F	1000 °F	1300 °F
304 SST	Good resistance to oxidation.	5600	4800	4700	4600	3400	2400	780
316 SST	Good resistance to corrosion. Better resistance to chemical attack than 304 SST.	5600	5400	5300	5200	4400	3200	1250
Carbon Steel	For non-corrosive service.	3700	3700	3700	3650	2000	–	–

(1) In case of an explosion, the integrity of the thermowell is maintained to the specified pressures.

Figure 4.2.2.2.2a – Materials of Construction

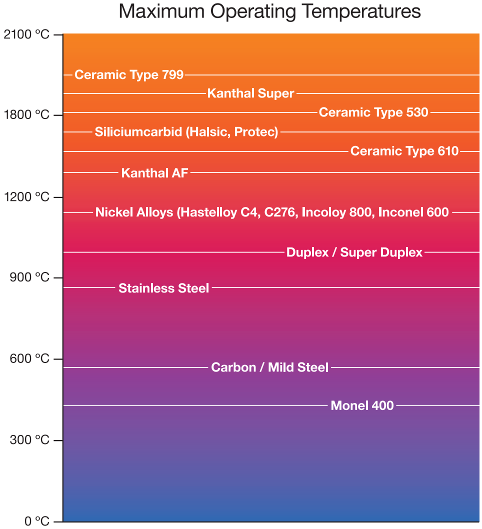


Figure 3.3.3.1b – Maximum Temperatures of Thermowell Materials

4.2.2.2.3 Determine Process Connection - Mounting Style

The choice of threaded, welded, flanged or Vanstone or lap joint flanged connection depends on the pressure rating of the installation, fluid velocity, type of fluid, conformance with codes and standards and plant piping specifications and preferences. See Figure 3.3.4a

Consider the following as a guideline:

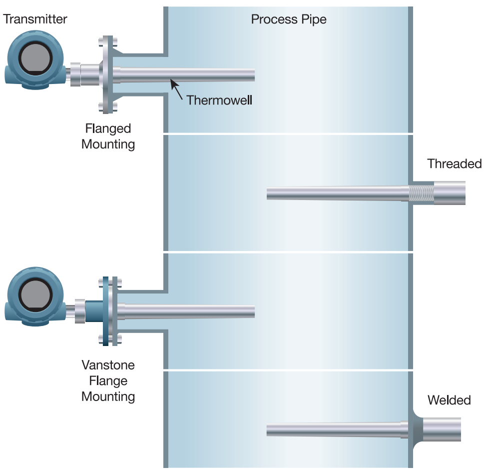


Figure 3.3.4a – Thermowell Mounting Methods

4.2.2.2.3.1 Threaded

Threaded thermowells are threaded into process piping or tank, which allows for easy installation and removal when necessary. While this is the most commonly used method of mounting, it has the lowest pressure rating of the three options. Threaded connections are also prone to leakage and therefore are not recommended for applications with toxic, explosive or corrosive materials.

4.2.2.2.3.2 Welded

Welded thermowells are permanently welded to process pipes or tanks. Thus, removal is difficult and requires cutting the thermowell out of the system. Welded thermowells have the highest pressure rating and are generally used in applications with high velocity flow, high temperature, or extreme high pressure. They are necessary where a leak-proof seal is required.

4.2.2.2.3.3 Flanged

Flanged thermowells are bolted to a mating flange that is welded onto process pipe or tank. They provide high pressure ratings, easy installation, and simple replacement. Flanged thermowells are used in applications with corrosive environments, high-velocity, high temperature, or high pressure.

4.2.2.2.3.4 Vanstone or Lap Joint

Vanstone or Lap Joint thermowells are mounted between the mating flange and the lap joint flange. These thermowells allow for the use of different materials for the thermowell coming in contact with the process and the overlaying flange which can save material and manufacturing costs and may be supplied as a forging.

4.2.2.2.4 Small Diameter Pipe Installations

Due to imperfect mixing and wall effects, the process temperature will vary with the fluid location in the vessel or pipe. For highly viscous fluids such as polymers the fluid temperature near the wall can be dramatically different from that at the centerline. Since these pipes are often less than 4 inches in diameter, there can be a problem in getting sufficient immersion length and still having the tip near the centerline.

For these applications an angled “T” fitting or elbow mounting should be considered. By installing the well with the tip facing the oncoming flow, good thermal contact is maintained and response is optimized. See Figure 4.2.2.2.4a for an elbow installation.

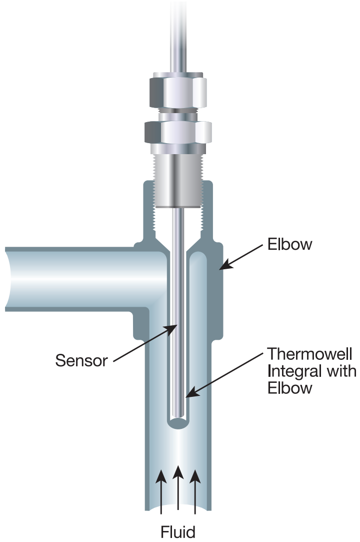


Figure 4.2.2.2.4a – Thermowell Elbow Installation

Figure 4.2.2.2.4b and Figure 4.2.2.2.4c shows alternative mounting options numbered according to preference. If the well is facing away from the flow, swirling may cause a less representative measurement. Using a stepped thermowell optimizes speed of response.

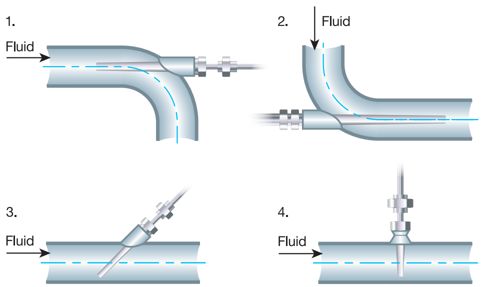


Figure 4.2.2.2.4b – Examples of Thermowell Insertions in Small Diameter Pipe Numbered by Preference

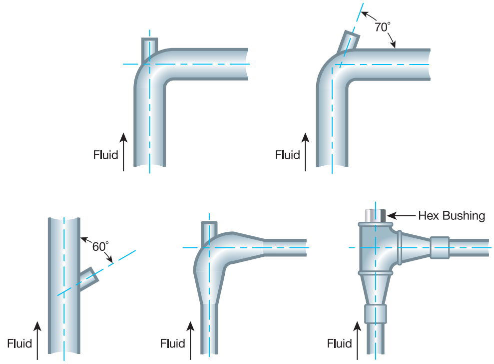


Figure 4.2.2.2.4c – Thermowell Angled Installation Options

> *TIP: Consideration must be given to impeded flow, pressure loss and pipe cleaning and flushing issues. Difficult-to-clean cavities may present a problem in sanitary applications.*

4.2.2.2.5 Determine Insertion Length

Confirm the pipe or tank diameter to determine the insertion length of the thermowell. There is no standard formula to determine the insertion length of the thermowell. Rather there are a few common practices that the process industry follows along with good engineering judgment. Ideally the tip of the thermowell should be located at an optimal process point, typically near the centerline, that is in turbulent flow conditions and is representative of the true process temperature. A measurement along a pipe wall would have an offset from the slower flow and wall temperature effects of the pipe. For tanks and other vessels, the internal flow pattern must be understood to ensure placement of the thermowell tip at the optimal point. A general guideline for insertion length into pipe for where optimal performance is required is ten times the diameter of the thermowell for air or gas and 5 diameters for liquids. Another guideline is at least one-third of the way into the pipe for liquids and two-thirds of the way into the pipe for air or gas measurements. The American Petroleum Institute (API) has a specific recommendation of using an insertion length of the sensing element plus 50 mm (2 inches).

Once the optimal insertion length has been determined a thermowell may be specified with the required "U" dimension. See Figure 4.2.2.2.5a and Figure 4.2.2.2.5b. The other dimensions of the thermowell may be determined by consideration of factors such as

- Insulation thickness
- Connection type
- Lagging length
- Length of any required extensions to protrude through the insulation layer
  - Be aware of connection head or integral transmitter housing dimensions added to the extension length relative to interference with nearby structures or equipment.

With the process connection, pipe or tank diameter, and the pipe insulation dimensions the overall dimensions of the thermowell can be determined. Consult vendor product data sheets for additional guidance.

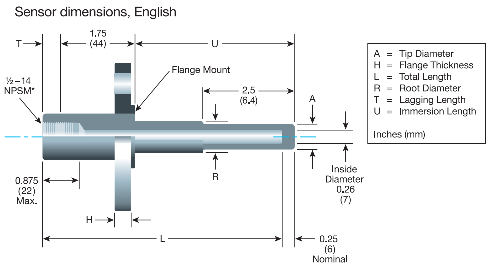
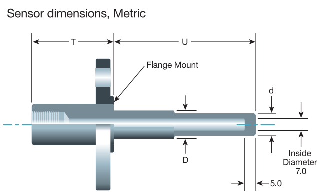


Figure 4.2.2.2.5a – Typical Thermowell Dimensional drawing (English)



Flange Size	D	d	T
1-in. 150 – 1500 lbs, DN 25	19	12.5	60
1 1/2 to 2-in. 150 – 600 lbs, DN40 - 50	26.5	18	60
1.5 to 2-in. 900/1500	26.5	18	80

Figure 4.2.2.2.5b – Typical Thermowell Dimensional drawing (Metric)

4.2.2.2.6 Selecting a Stem Profile Style

Factors to be considered when selecting a stem style include the process pressure, the required speed of response of the measurement, the drag force of the fluid flow on the well and the wake frequency.

The stem or shank is the part of a thermowell that is inserted into the process piping or vessel. The common stem profiles are straight, stepped, and tapered. See Section 3.3 and Figure 3.3.3.3a. In general, tapered or stepped stems provide faster response, create less pressure drop, and are less susceptible to conduction error due to thermal lag and to failure due to vibration from wake frequency.

Refer to the Thermowell Chapter (Section 3.7.1) Fluid Flow Induced Vibration Considerations for complete detail.

WHAT IS THE RECOMMENDED INSERTION LENGTH FOR A THERMOWELL?

Confirm the pipe or tank diameter to determine the insertion length of the thermowell. There is no standard formula to determine the insertion length of the thermowell. Rather there are a few common practices that the process industry follows along with good engineering judgment. Ideally the tip of the thermowell should be located at an optimal process point, typically near the centerline, that is in turbulent flow conditions and is representative of the true process temperature.

A measurement along a pipe wall would have an offset from the slower flow and wall temperature effects of the pipe. For tanks and other vessels, the internal flow pattern must be understood to ensure placement of the thermowell tip at the optimal point. A general guideline for insertion length into pipe for where optimal performance is required is ten times the diameter of the thermowell for air or gas and 5 diameters for liquids. Another guideline is at least one-third of the way into the pipe for liquids and two-thirds of the way into the pipe for air or gas measurements. The American Petroleum Institute (API) has a specific recommendation of using an insertion length of the sensing element plus 50 mm (2 inches).

Refer to:

4.2.2.2.5 – Determine Insertion Length

See also:

Figure 4.2.2.2.5a – Typical Thermowell Dimensional drawing (English)

Figure 4.2.2.2.5b – Typical Thermowell Dimensional drawing (Metric)

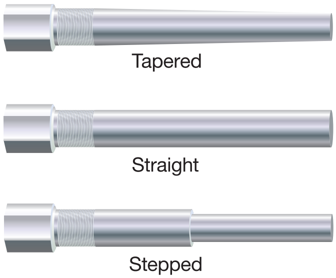


Figure 3.3.3.3a – Thermowell stem profiles

Consider the following as a guideline and note that complete detail on each type can be found in Chapter 3.3

4.2.2.2.6.1 Straight

Straight profile thermowells have the same diameter along the entire immersion length. They have the highest pressure rating of the three profile types but, accordingly, they present the largest profile to the process medium and therefore have a high drag force.

4.2.2.2.6.2 Stepped

Stepped profile thermowells have two straight sections with the smaller diameter at the tip. They have the lowest drag force profile and have reduced pressure ratings than the straight type.

4.2.2.2.6.3 Tapered

Tapered profile thermowells have an outside diameter that decreases uniformly from root to tip. These are a compromise between the other two types for drag force profile and pressure rating.

4.2.2.3 Reusing an existing thermowell

If only the sensor is being replaced, determine if the existing thermowell is satisfactory for continuing use. It would be appropriate to review the original selection criteria in light of the guidance discussed above. There is no time like the present to correct an improper installation. If the old sensor was not a spring loaded design, an upgrade to this design could increase response and reduce the potential for vibration damage. Historically older installations often did not adequately take wake frequency into account. It is suggested that a new calculation be performed using the guidance in the latest version of ASME PTC 19.3 TW-2010. (Note that the standard covers many – but not all – configurations and additional engineering judgment may be required for those applications to complete an analysis.) Wake frequency is a determining factor in selecting a thermowell for a high-velocity application. Most manufacturers have a software tool to provide an analysis of the wake frequency effects that predicts probability of failure of the thermowell. More detail is in 2.2.3.7.1 Fluid Flow Induced Vibration Considerations section of the Thermowell Chapter. Once reuse of the thermowell is confirmed, determine the sensor insertion length from data on the sensor being replaced, by adding the well bore depth extension length and connection head allowance or by actual measurement. Vendor product data sheets typically provide guidance on this selection process.

4.2.2.4 Surface Mounting

Surface mounting is often an efficient and convenient installation method that is used when it is impractical or impossible to insert a sensor assembly into the process. For example, this situation may exist because of frequent use of a “pig” to remove process material that builds up in the piping and the pig cannot pass by obstructions such as a thermowell protruding into the pipe. See Figure 3.2.3.5.2a. Or it may be an added measurement where an expensive process shutdown would be required to install the new thermowell. Surface measurement is only as reliable as the temperature on the surface of the pipe or vessel. In general, the goal is to maximize heat conduction from the pipe or vessel surface to the sensing element. Sensors can be mounted with adhesives, screws, clamps, or welds and recognizing that good thermal contact is necessary. See Figure 3.2.3.5.2b.

Thermal insulation is used to minimize the loss of heat energy from the surface of the pipe to its surroundings and should cover the sensor and the lead wires for some distance to minimize any conduction heat losses to the leads. See Sensor Chapter section 3.2.3.5.2 - Surface Mounting for more information.

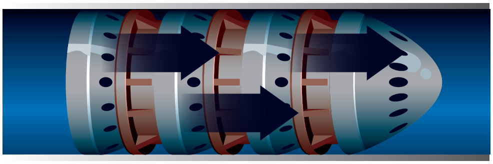


Figure 3.2.3.5.2a – Piping Pigs

Figure 3.2.3.5.2b – Surface Mount Sensor – Pipe Clamp

4.2.3 Sensor Selection

While several types of temperature sensors may be used, resistance temperature detectors (RTDs) and thermocouples (T/Cs) are most common in the process industry. See Figure 3.1.2.1a A detailed discussion of sensors may be found in the Sensors Chapter of this handbook in Sections 3.2.3 and 3.2.4.

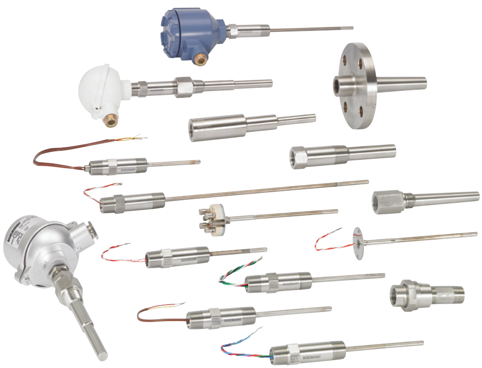


Figure 3.1.2.1a – Sensor Family

In the "Understanding Your Temperature Measurement System" section of this Engineering and Design Chapter a series of questions were provided to assist in system selection decisions. Those questions associated with sensor selection are listed below along with insights into the selection implications:

- Is the requirement to monitor temperature trends or an actual controlled value?
  - Monitoring trends does not typically require high precision suggesting that either a T/C or an RTD would serve well enough.
- A basic transmitter or monitoring system input card would fill the need for signal conditioning.
  - For control applications more insight is required
- What is the temperature range? The control point? Its maximum temperature? Its minimum temperature?
  - If the maximum temperature to be measured is over 850 °C, a T/C is the only choice.
  - For most other applications either sensor would serve
- Are there established plant preferences for choice of sensor that may influence your selection? While Proven-in-Use is a valuable consideration, do not fall into the trap of following "we have always done it that way" mentality
  - Many plants have adopted the position that they will use an RTD unless limited by a high temperature application where using a T/C is the only practical choice
  - Others use specific sensor types on specific applications based on successful experience. It is often wise to follow this trend
- Are certain sensor types kept in inventory?
  - Using a normally stocked sensor may save inventory costs for spares assuming that the stocked model meets the requirements of your application
- What is the control precision requirement?
  - For example furnace temperature control may tolerate ± 10 °C while a pharmaceutical batch process may require ± 0.25 °C or better.
  - If the accuracy requirement is for better than ± 2 °F, an RTD is the better choice
  - Long term stability highly favors an RTD
  - Best accuracy is provided by a spring loaded wire wound design
  - See Sensor Chapter 3.2.3.11.2, RTD Accuracy/Interchangeability and 3.2.4.8, Thermocouple Accuracy
- What is the speed of response to temperature change requirement?
  - Spring loaded sensors and stepped thermowells optimize speed of response
  - Use thermally conductive oil to fill the voids between the sensor and the inside bore of the thermowell to increase the speed of response

  – See Sensors Chapter 3.2.5 – Measurement Response Time Considerations

- Is there a significant ROI for best possible accuracy and stability? (Custody transfer, energy optimization or distillation column throughput are examples providing significant ROI)
  – Consider using an RTD with sensor-transmitter matching option for system accuracy as good as 0.015 °C
- What are the costs associated with a measurement failure? Production downtime costs? Off-spec product that requires reprocessing or selling at a reduced price? Energy inefficiency? Troubleshooting and maintenance time? Dangerous runaway reactions?
  – Even a one degree error could cost thousands of dollars in wasted energy per year
  – Any of these "cost of ownership" consequences suggest using a high quality transmitter integrally mounted with a quality sensor in a well-engineered system
- Most often this will be a high quality RTD
- What is the frequency and severity of the piping / vessel vibration (typical and maximum?)
  – High vibration suggests using a thin film spring loaded RTD sensor
- Refer to Sensors chapter section 3.2.3 on RTDs
  – In some cases a helical coil wire wound RTD will perform better
- Refer to Sensors chapter section 3.2.4 for T/C
  – A heavy gauge T/C is another possible alternative
  – Consult vendor product data sheets for specifications
- Is this measurement part of a safety instrumented system?
  – If yes refer to Transmitter chapter section 12.0, Safety Certified Transmitters and to the Appendix
  – In general, use the highest reliability system as is practical as described above.

4.2.3.1 Comparison of RTD vs. T/C

Over the years there have been purported advantages for using a T/C but most of these are of little relevance for industrial process applications.

HOW TO CHOOSE THE RIGHT SENSOR TECHNOLOGY (RTD OR T/C)

Over the years there have been purported advantages for using a T/C but most of these are of little relevance for industrial process applications. Although some T/Cs made with heavy gauge wire are quite rugged with a high tolerance for vibration, in general, an RTD properly selected and installed in a properly designed thermowell is suitable for challenging high velocity steam or liquid applications and even applications in the nuclear industry.

Refer to:

4.2.3.1 – Comparison of RTD vs. T/C

4.2.3.1.1 – RTD Characteristics and Advantages

4.2.3.1.2 – T/C Characteristics and Advantages

Table 4.2.3.1.2a – Sensor Comparison Table

Although some T/Cs made with heavy gauge wire are quite rugged with a high tolerance for vibration, in general, an RTD properly selected and installed in a properly designed thermowell is suitable for challenging high velocity steam or liquid applications and even applications in the nuclear industry.

T/Cs are said to be less expensive but when the cost of extension wire, more frequent calibration and replacement, and lower accuracy impacts on the process are considered this advantage disappears. In fact, in many cases, the cost of ownership of a T/C installation easily exceeds that of an RTD installation.

The most viable reason for using a T/C is if the measured temperature range exceeds what is practical for an RTD. The RTD potential upper limit is about 850 °C (1,500 °F).

For applications where only trends are monitored and errors of several degrees can be tolerated, multipoint or single T/C assemblies may have a cost advantage when wired to a multichannel transmitter or a multiplexer.

For process control applications and especially for SIS applications, a properly designed and installed RTD system is clearly the better choice for temperatures below 500 °C (900 °F). At higher temperatures up to 850 °C there can be increased drift that may nullify some of the accuracy advantage. See Figure 4.2.3.1a.

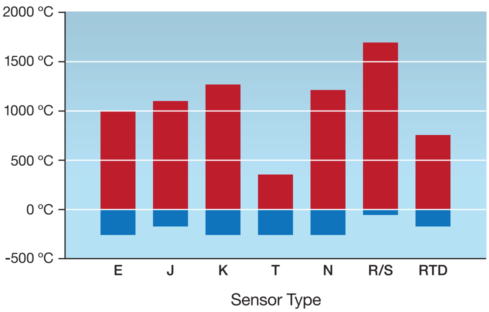


Figure 4.2.3.1a – Potential Sensor Ranges in °C

4.2.3.1.1 RTD Characteristics and Advantages

Refer to section 3.2.4 in the Sensors Chapter for a detailed discussion of RTDs

- Potential range is -200 to 850 °C
- Much better repeatability than a T/C
- Long term drift is predictable while a T/C drift is erratic. This provides the benefit of less frequent calibration and therefore lower cost of ownership
- Much better sensitivity than a T/C. When used with a high resolution transmitter a much more precise measurement can be made
- Excellent linearity. When coupled with the linearization performed in a quality transmitter, a precision of about 0.1 °C is possible which is much better than what is possible with a T/C
- Can be used with standard copper lead wires and connection cables
- May be provided with CVD constants that allow matching the sensor to a transmitter to produce extraordinary accuracy (Up to 0.015 °C)
- Demonstrate negligible hysteresis
- Normally supplied as 4-wire design and, when used with a quality transmitter, lead length is inconsequential
- Low susceptibility to EMI and RFI

4.2.3.1.2 T/C Characteristics and Advantages

Refer to section 3.2.4 in the Sensors Chapter for guidance in selecting the T/C type best suited to your measurement range and application

- Practical range depends on T/C type and can be as low as -270 and up to 2300 °C
- Linearity depends on type and can be extremely non linear over wide ranges This is compensated to a degree by the linearization performed by a transmitter
- Measurement accuracy is dependent on an accurate Cold Junction Compensation (CJC) as performed by a transmitter or other signal conditioner
- Subject to hot junction degradation over time and especially at higher temperatures causing unpredictable and erratic drift
- Must be used with matching T/C extension wire which is also subject to degradation
- Susceptible to EMI and RFI. (Use with an integrally mounted transmitter minimizes this effect)
- Heavy gauge wire construction can withstand high vibration
- When used in a thermowell, a T/C has a response time about the same as an RTD. Bare element installations are faster but are not widely used in the process industries due to safety concerns of potential leakage and exposure of the sensor to adverse process conditions
- T/Cs are available with standard grade tolerances or special grade tolerances called Class 2 and Class 1 respectively with Class 1 having about twice as good of a tolerance specification. However, over time and depending on the application, the T/C degradation may nullify this advantage.

Refer to Table 4.2.3.1.2a for a detailed comparison of RTDs and T/Cs.

4.2.3.2 Specifying a Sensor

4.2.3.2.1 Specifying an RTD Assembly

The following considerations are relevant to a proper selection of an RTD to best meet the requirements of your application:

- Refer to section 3.2.3 in the Sensors Chapter for a detailed discussion of RTDs
- Consider plant standards and recommended practices for guidance
- It is typically most cost effective to specify and order the RTD as part of a factory assembled tested and calibrated measurement system complete with the thermowell and transmitter to assure proper fit and function. Approximately 50% savings vs. ordering individual components and assembling, testing and calibrating in the field.

Attribute	RTD	Thermocouple
Accuracy Interchangeability	Class A: ± [0.15 + 0.002 (t)] Class B: ± [0.30 + 0.005 (t)] Per IEC 60751	Typical is ± 1.1 °C or ± 0.4% of measured temperature (Greater). Depends on Type and Range. Degraded by extension wire.
Stability	± 0.05 °C per 1000 Hrs at ≤ 300 °C. Greater at higher temperatures. Wire wound better than thin film.	Highly dependent on T/C type, quality of the wire and operating temperature. Typical is ± 2 to 10 °C per 1000 Hrs.
Speed of Response in Thermowell Installation in Liquid	For 6mm sensor about the same as T/C.	For 6mm sensor about the same as RTD. Slightly faster for 3mm sensor.
Calibration	Easily recalibrated for long service life. Best accuracy with Sensor-Transmitter Matching.	Limited to in situ comparison to "Standard T/C".
Potential Temperature Range	-200 to 850 °C	-270 to 2300 °C
Life Span	Many years. Shorter at higher temperatures.	Degradation indicates frequent replacement. Much shorter at high temperatures. Higher life cycle costs.
Installation Considerations	Use standard copper wire. Good EMI and RFI immunity.	Requires expensive matching extension wire. Low level signal is very susceptible to EMI and RFI.
Vibration Tolerance	Thin film design is very good.	Larger wire diameters are very good.
Life Cycle Cost	Lower.	Higher.
Purchase Cost	Thin film design about the same. Wire wound higher.	Types R and S most expensive.
System Performance with Transmitter	Always better below 650 °C.	Order of magnitude lower.

Table 4.2.3.1.2a – Sensor Comparison Table

- Consider what styles may be kept in inventory
- A thin film design will be the least expensive and fastest responding choice
- A Spring-loaded thin film design is almost always the best choice for fastest time response and least susceptibility to vibration. See Figure 3.2.3.1.2b. However, some designs of helical style wire wound elements are another good choice. See Figure 3.2.3.2.2a.

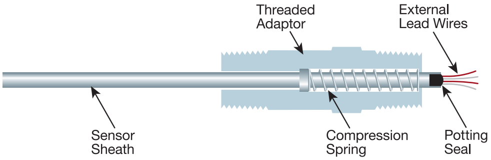


Figure 3.2.3.1.2b – Spring Loaded Threaded Style

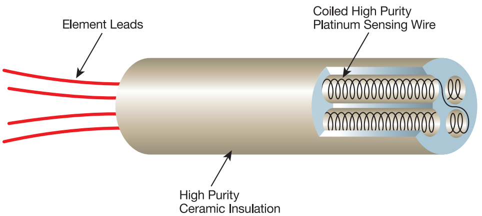


Figure 3.2.3.2.2a – Coiled Suspension RTD Sensor

- Best performance and accuracy is achieved by using 4-wire sensor-transmitter systems since they are immune from the lead wire resistance errors generated by 2 and 3-wire systems. See section 3.2.3.1.3.1 in the Sensors Chapter for a discussion.
- Mounting is dependent on choice of local or remote mounting with the transmitter and the connection head style chosen. A DIN style design is an option for some transmitter or connection head options while a threaded style could be chosen for direct mounted dual compartment and some other style housings.
- Immersion length must be suitable for the thermowell bore depth that has been specified. The vendor Product Data Sheet will provide guidance in determining this dimension.
- For improved speed of response specify that the void between the sensor and the well bore be filled with thermally conductive fluid.
- Consider dual element sensors for redundancy and for the Hot Backup® feature or where the measurement may be connected to two separate systems or devices. See Figure 3.2.3.1.1a.

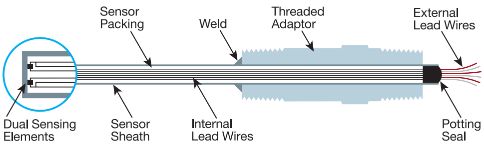


Figure 3.2.3.1.1a – Dual Element RTD

4.2.3.2.2 Specifying a Thermocouple Assembly

In addition to the considerations mentioned above for specifying an RTD, there are several other factors to be considered for selecting the best T/C type, style, and mounting options.

- Refer to section 3.2.4 in the Sensors Chapter for guidance in selecting the T/C type best suited to your measurement range and application.
- It is typically most cost effective to specify and order the T/C as part of a factory assembled tested and calibrated measurement system complete with the thermowell and transmitter to assure proper fit and function. Approximately 50% savings vs. ordering individual components and assembling, testing and calibrating in the field.
- For profiling applications, consider multipoint assemblies.
- Ensure that the proper T/C extension wire is specified. It must match the T/C type and be produced in accordance with the same color code standard as the T/C.
- Choose either grounded or ungrounded sensor design. While grounded are somewhat faster responding they are also more susceptible to noise pickup from the process and more prone to junction poisoning. Note that the response time of the measurement is mostly dependant on the thermowell mass as opposed to the sensor mass.
- Consider a dual element design where redundancy, the Hot Backup® feature or Sensor Drift Alert may be a benefit or where the measurement may be connected to two separate systems or devices. Dual elements can be isolated or unisolated configurations. Isolated junctions may not read identical temperatures but can identify drift due to poisoning of one of the elements. If one junction fails, the second junction is not necessarily affected. Un-isolated junctions measure identical temperature to increase the integrity of the measurement point. However, if one junction fails, it is likely that both junctions will fail at the same time. Refer to Figure 3.2.4.3.1a.

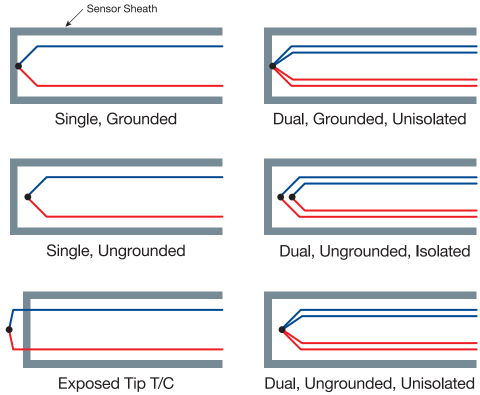


Figure 3.2.4.3.1a – T/C Junction Configurations

4.2.3.3 Ordering Details

Once it has been decided to use an RTD or T/C based on the above criteria, there are a variety of details that must be specified to build a model number of your specific sensor assembly. See Figure 4.2.3.3a for typical model numbers. Using your company forms or those supplied by ISA or your vendor and using the vendor product data sheet as a guide for available options, complete the various sections of the form that define the design of your sensor system including:

Tip: Refer to Temperature Measurement Basics, Chapter 3, Section 3.2 and 3.3 for detail on any of the following topics

Note: This example is for a sensor and thermowell assembly

- Sensor type
  - RTD
    - 100Ω (Most common); Others: 200Ω; 500Ω; 1000Ω
    - 4-wire design (Best choice for most applications)
  - T/C
    - Type: E, J, K, T, etc.
- Connection head Style
  - Material; Terminals; Cover
- Sensor Mounting Style
  - General Purpose; Spring-Loaded; Bayonet
  - Standard or High Temp Construction

- Extension Detail
  - – Nipple Coupling; Nipple Union
  - – Length
- Thermowell Material
  - – Consistent / Compatible with pipe or vessel
  - – Consider pressure, erosion and corrosion
- Thermowell Process connection See Figure 3.3.4a
  - – Threaded; Flanged; Weld-in
    - Flanged for ease of replacement
    - Weld-in for high pressure applications

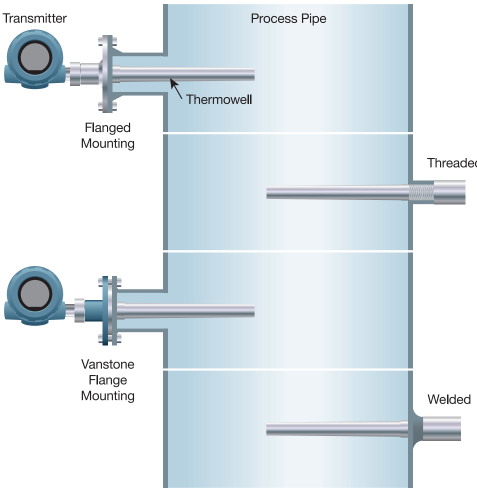


Figure 3.3.4a – Thermowell Mounting Methods

- Thermowell Style See Figure 3.3.3.3a
  - – Straight, Stepped, Tapered
    - Stepped offers fastest response
- Fluid velocity and viscosity if wake frequency calculations are required

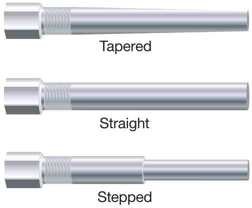


Figure 3.3.3.3a – Thermowell Stem Profiles

- Sensor length See Figure 4.2.2.2.5a
  - – Overall length (L) includes insertion length (U), extension (E), wrench and thread allowance, lagging nominal allowance (T), thread engagement into connection head , and allowance for spring-loaded style

Sensor dimensions, English

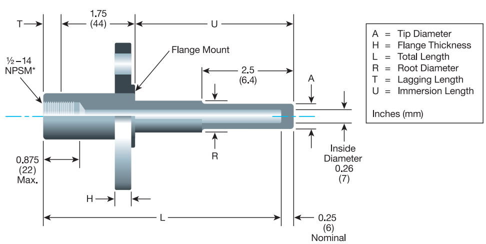


Figure 4.2.2.2.5a – Thermowell Dimensions

- Calibration Requirements
  - – Consider Total Probable Error (TPE) of system vs. process requirements
  - – Let the calculations drive the decision
  - – Customer specified range
  - – CVD constants for transmitter-sensor matching (Refer to section 3.2.3.12 for more detail)
    - Highest accuracy
- Agency Approvals
  - – FM; CSA; IECEx; KEMA/CENELEC

Model Number Example (English)

	Model	Lead Wire Termination	Sensor Type	Extension Type	Extension Length	Material Code	Immersion Length	Mounting Style	Additional Options
Typical Model Number	0078	N	21	A	30	A	075	T22	E5

Model Number Example (Metric)

	Model	Connection Head	Lead Wire Termination	Sensor Type	Extension Type	Extension Length	Thermowell Material	Immersion Length	Mounting Style	Additional Options
Typical Model Number	0065	C	2	1	D	0135	D	1225	T12	X8

Figure 4.2.3.3a – Typical Sensor Model Number Examples

4.2.4 Transmitters

The transmitter converts the sensor measurement input signal to high level robust output signal. The output signal can be either analog or digital, both of which are highly accurate and reliable with strong noise immunity and may be transmitted over long distances. The most common analog signal is 4-20mA with HART® protocol. The digital communication protocols are HART (including WirelessHART™), FOUNDATION™ Fieldbus, and Profibus, all of which are open and interoperable standards. The use of digital technology adds flexibility to the output of each transmitter, enabling transmission of more than one temperature value as well as large amounts of diagnostic information.

Refer to the Temperature Measurement Basics in Chapter 3, Section 3.1.3 - *Output Options* for more detail

Transmitters are available in a variety of housing styles that may be mounted into any of a wide selection of enclosures that are available in many different materials of construction. Refer to Figure 3.1.1a. They may be mounted integrally with a sensor/thermowell assembly at the process measurement point and transmit either a hard-wired or wireless signal. Alternatively, they can be mounted remotely from the sensor assembly in any of several types of enclosures. They can be configured locally or remotely and can provide local indication. They have an array of standard and optional performance features to provide remarkable functionality. Systems may be provided to meet virtually any agency approval requirement.

Refer to the Temperature Measurement Basics Chapter 3 Section 3.1.10 - *Transmitter Styles; Housing and Mounting Options* for more detail.

Figure 3.1.1a – Transmitter Styles

4.2.4.1 Performance and Functionality Considerations

From the discussion in section 4.1.2 of the *Understanding Your Temperature Measurement System* section you should have analyzed your application to the point where you understand all aspects in detail. It is impractical to specify the best possible transmitter for simple applications where a basic model will provide adequate performance. These applications could include monitoring trends or where accuracy requirements are not as stringent and optimal accuracy and performance is not beneficial.

However, for systems requiring high accuracy and /or high reliability performance, a top-of-the-line model mounted into a dual compartment housing and installed as close as possible to the measurement point is a wise choice. See Figure 3.1.10.2a. As stated in the introduction, cost of ownership considerations should drive your selection.

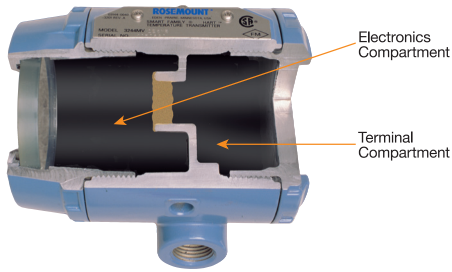


Figure 3.1.10.2a – Dual Compartment Housing

Most transmitters accept RTD, T/C, mV, or ohm signals. Many transmitters have a dual-input capability, allowing them to accept inputs from two sensors. Duals sensors offer the option of redundancy with the Hot Backup® feature, monitoring for sensor drift, and allows for a measurement of differential and average temperatures.

Where a large number of temperature measurement points are close together a multi-input transmitter may be specified. These high density transmitters minimize installation costs in applications such as heat exchangers, boilers, chemical reactors, and distillation columns by reducing purchase, installation, operation and maintenance costs vs. multiple transmitters. They are also often used for temperature profiling of furnaces and reactors. See Figure 3.1.10.3b.

Figure 3.1.10.3b – High Density Field Mount Installation

4.2.4.2 Mounting Location

Mounting location is another guiding factor in transmitter style selection that begins with determining where the transmitter will be mounted relative to the sensor. Where possible and practical, transmitters should be mounted close to the measurement point to minimize potential EMI and RFI noise pickup. This is especially important for low level T/C signals which are especially susceptible to noise.

High process fluid temperature radiates from the pipe or vessel causing a high ambient temperature situation that may be unsuitable for close coupled transmitter mounting. This situation may be addressed by installing an insulation layer and/or by using sensor extensions to position the transmitter housing further away from the heat source. See Figure 4.2.4.2a for an example of the temperature effects on the transmitter.

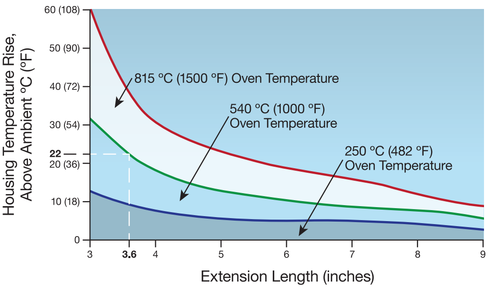


Figure 4.2.4.2a – Transmitter Housing Temperature Rise vs. Extension Length for a Test Installation

Example:
The maximum permissible housing temperature rise (T) can be calculated by subtracting the maximum ambient temperature (A) from the transmitter's ambient temperature specification limit (S). For instance, if A = 40 °C.

T = S - A
T = 85 °C - 40 °C
T = 45 °C

For a process temperature of 540 °C (1004 °F), an extension length of 91.4 mm (3.6 inches) yields a housing temperature rise (R) of 22 °C (72 °F), providing a safety margin of 23 °C (73 °F). A 152.4 mm (6.0 inch) extension length (R = 10 °C (50 °F)) offers a higher safety margin (35 °C (95 °F)) and reduces temperature-effect errors but would probably require extra transmitter support. Gauge the requirements for individual applications along this scale. If a thermowell with lagging is used, the extension length may be reduced by the length of the lagging. See Figure 3.3.5a.

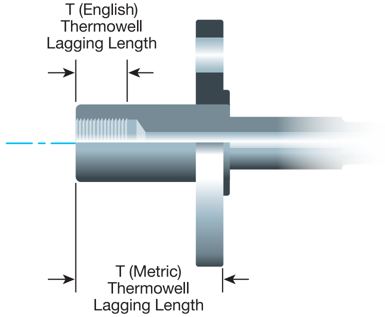


Figure 3.3.5a – Lagging Dimension

If the extension length that would be required to prevent excessive transmitter housing heating becomes unwieldy, consider remote mounting the transmitter. Remote mounting is also a good option when the pipe or vessel is under high vibration conditions. Frequently, transmitters are remote-mounted away from a connection head to make the instrument more accessible for calibration and maintenance, or to simply make it easier to view the LCD. It may also be desirable to group a number of transmitters together on an instrument stand for optimum operator and maintenance availability. These stands should be located where they can be easily accessed but where damage is unlikely.

Another alternative is high density DIN rail mounting into a local field mounted cabinet. However, this option does not support explosion proof requirements and should not be used in corrosive or excessively humid environments.

4.2.4.2.1 Additional Mounting Considerations

There are a variety of choices for mounting a transmitter that are driven by process conditions at the point of measurement, plant standards and policies, and user preference.

A methodical approach of reviewing all related factors will very likely present the best choice. Here are some examples of questions that must be answered to drive the selection process.

- Is the ambient temperature expectation at the measurement site within the limits of the transmitter specification?
  – If yes integral mounting is acceptable
- Is the measurement site easily accessible?
  – If yes integral mounting is acceptable
- Is local temperature indication required?
  – Specify an LCD indictor option
  – Refer to Transmitter Chapter, Section 3.1.11.2 - Local Display
- Can operator see display if assembly is integrally mounted at the measurement point?
  – If yes integral mounting is acceptable
  – If not, a remote mount option is required
- Is there high vibration at the measurement point?
  – If yes, a remote mount option is required
  – If no, integral mounting is acceptable
- What is the area classification? What is the approval agency?
  – Select a housing option that offers the protection and certification that is required. Check P&IDs, plant standards and vendor product data sheet
- Does the plant site require Intrinsically Safe (IS) installation?
  – If yes, specify a housing with IS certification
- Are there sources of EMI, RFI or electrical surges near the measurement point?
  – If yes integral mounting is desirable
  – Refer to Transmitter Chapter, section 3.1.2.4.1 - Noise filtering and 3.1.11.3 - Transient Protection
- Is this measurement associated with a SIS?
  – If yes, specify a model with appropriate certifications for the SIL required.
  – A top-of-the-line system offering maximum reliability and performance is most often the best choice for safety related applications
  – Verify the safety requirements with the designated Certified Fuctional Safety Expert (CFSE)
  – Refer to Transmitter Chapter, Section 3.1.12 - Safety Certified Transmitters and the SIS Section 8.3 in the Reference Chapter
- Is there a sanitary consideration?
  – If yes, specify appropriately certified housing and thermowell assembly
  – Refer to Transmitter Chapter, Section 3.1.10.4 - Sanitary Housing
- Is there a corrosive environment?
  – If yes, verify suitability of selected housing material with the contaminants present
  – If material is not suitable a remote mount may be required

Tip: Many times a site inspection and consultation with process engineering and operations will greatly facilitate the choice of the optimal system.

4.2.4.3 Model Styles

The most common mounting styles are:

Head-mount transmitters are compact disc shaped transmitters most often mounted within a connection head which can be mounted in the field. Most common styles are DIN A and DIN B which differ slightly in dimensions and mounting method. See Figure 3.1.11.2.2a.

Figure 3.1.11.2.2a – Head Mounted Transmitter

Dual-compartment transmitter housings are a two part housing, often known as field mount, that isolates the transmitter electronics module from the terminal strip compartment to protect it from exposure to harsh plant environments. The terminal compartment contains the terminal and test connections for the sensor and signal wires and provides access to the terminal block for wiring and maintenance while isolating the transmitter electronics. See Figure 3.1.2.3a.

Figure 3.1.2.3a – Dual compartment transmitter

Rail-mount transmitters are thin rectangular transmitters that are typically attached to a DIN-rail (G-rail or top-hat rail) or fastened directly onto a surface. This provides a compact high-density installation where a number of rail-mount transmitters can be placed very closely together on the same DIN-rail. Unlike the field-mount transmitters, the DIN style are not designed for harsh environments nor can they be used in areas designated as explosion-proof. See Figure 3.1.10.3a.

Figure 3.1.10.3a – Rail-mount Transmitters

4.2.4.4 Transmitter Standard Features

Smart transmitters offer many standard features including noise filtering, galvanic isolation, linearization of nonlinear input signals, cold junction compensation (CJC) for thermocouples, configurable input selection, bidirectional communication with the host, and internal and external self diagnostics.

In addition there are many optional features that can be utilized to enhance the measurement reliability and functionality. All of these are discussed in detail in sections 3.1.6 and 3.1.8 of the Transmitter Chapter and are listed below with reference sections.

4.2.4.5 Intelligent Filtering Features and Options

Tip: Refer to the Transmitter chapter sections listed below for a detailed explanation of each feature or option and then review your application requirements to determine which options would provide the added reliability and functionality needed.

- ***3.1.6.1 - Damping***
- ***3.1.6.2 - Open Sensor Holdoff***
- ***3.1.6.3 - Transient Filtering***
- ***3.1.6.4 - EMF Compensation***
- ***3.1.6.5 - Line Voltage Filter***
- ***3.1.6.6 - The Hot Backup® feature***
- ***3.1.6.7 - Sensor Drift Alert***
- ***3.1.6.8 - Thermocouple Degradation***
- ***3.1.6.9 - Minimum and Maximum Tracking***

4.2.4.6 Diagnostics

Tip: Refer to the indicated sections of the Transmitter Chapter to better understand the functionality and benefits of the various diagnostic functions.

3.1.8 - Diagnostics

- ***3.1.8.1 - Internal Diagnostics***
- ***3.1.8.2 - External Diagnostics***
- ***3.1.8.3 - Open/Short Sensor Diagnostics***
- ***3.1.8.4 - Measurement Validation Diagnostic***
- ***3.1.8.5 - Diagnostics Log***

4.2.5 Installation Best Practices

The following sections are suggested best practices for designing, selecting, installing and configuring a properly engineered temperature measurement solution for your application.

4.2.5.1 Thermowell Installation

- Ensure that the proper thermowell design has been purchased and it is accordance with the specification for pressure rating and materials of construction Figure 3.3.4a.
- Secure the proper permits and permissions to make the penetration into the pipe or vessel.
- Ensure that the pipe or vessel has been properly drained and cleaned as may be required. This is especially important for toxic or flammable materials.
- Follow the applicable vessel code requirements for weld certification and leak testing as is specified.

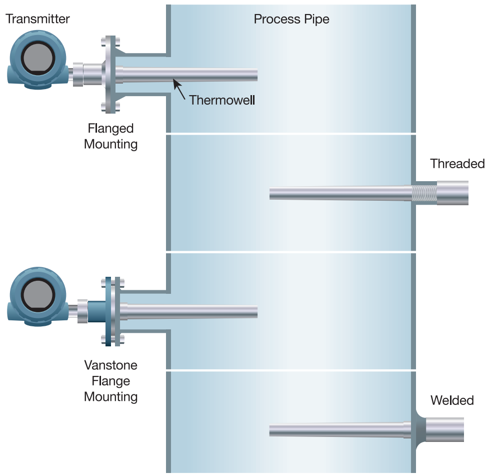


Figure 3.3.4a – Thermowell Mounting Methods

4.2.5.2 Transmitter Installation

4.2.5.2.1 Configuration

Depending on the ordering specification, the sensor-transmitter assembly may or may not have been factory configured and calibrated to the specific process requirements. It is always prudent to verify all settings to ensure that they conform to the latest revisions of the loop drawings. The vendor User's Manual will provide guidance on such things as ranging, alerts, alarms, damping, various intelligent filtering settings etc.

4.2.5.2.2 Calibration

Once the transmitter is configured, calibration may be required. This calibration may have been performed by the manufacturer in which case it should not be changed. It may be prudent to verify the sensor-transmitter integrity however by using temperature baths or blocks to exercise the system over its range. Refer to Maintenance Chapter 5, Section 5.7 for more calibration detail.

4.2.5.2.2.1 Transmitter-Sensor Matching

A more precise compensation for RTD inaccuracies is provided by Transmitter-Sensor Matching using the transmitter's factory programmed Callendar–Van Dusen equation. This equation describes the relationship between resistance and temperature of platinum resistance thermometers (RTDs). The matching process allows the user to enter the four sensor specific Callendar-Van-Dusen constants into the transmitter. The transmitter uses these sensor-specific constants in solving the CVD equation to match the transmitter to that specific sensor thus providing outstanding accuracy. System accuracies of +/- 0.025 °F are possible (+/- 0.014 °C). See Figure 3.1.4.3.3a.

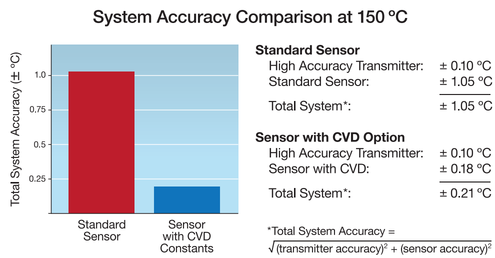


Figure 3.1.4.3.3a – Sensor-Transmitter Matching

4.2.5.2.3 Installation Detail

Frequently the transmitter is integrally mounted with the sensor and installed into a thermowell. Alternatively the transmitter is remotely mounted as near the measurement point as is practical on a rack, pipe-stand or on a bracket. A connection head should be used in these installations such that the sensor leads may be kept as short as possible to reduce noise pickup and potential damage. There are typically plant standards and loop drawings that dictate the details of transmitter mounting and wiring but in general, locations are selected to facilitate access for viewing of indicators if so provided, calibration and maintenance and away from areas of potential physical damage, splashing or dripping. See Figure 3.1.10.2b.

Transmitters should be positioned higher than the conduit runs and with the conduit connection at the bottom to minimize potential egress of moisture from leaking conduit seals. Threaded connections may require PTFE tape. A pressure test should be completed and documented before wiring is installed and power is applied.

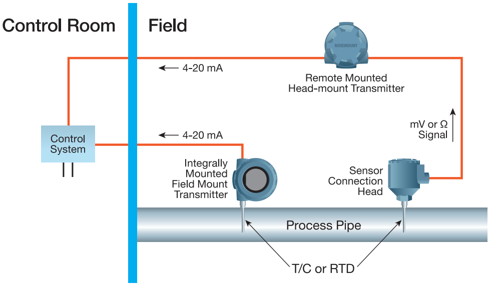


Figure 3.1.10.2b – Installation Options

4.2.5.2.3.1 Wireless Considerations

There are installation issues for wireless instrumentation that are unique including:

- Proper height from ground or structure and with respect to neighboring device (s) Figure 4.2.5.2.3.1a
- Mounting position with respect to nearby structures or devices (305 mm(1 foot) minimum)
- Line of site to "neighbor" device
- Proper antenna for distance required (high gain / low gain)
- Follow proper configuration guidelines in vendor manual using typical HART configuration tools (Field configurator, laptop, asset management system)

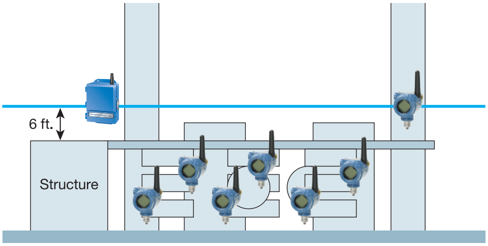


Figure 4.2.5.2.3.1a – Wireless Mounting Guideline

4.2.5.2.4 Wiring

Ideally the proper cable types have been specified during the design phase of the project. In all cases the conductors should be twisted and shielded with an outer insulated sheath selected to be in conformance to the environmental conditions where the wiring trays will be installed. For multi-conductor cables there are many designs. Some have individually shielded pairs with an overall shield with drain wire for maximum noise protection and have an overall insulated sheath.

The sensor wires and output cables should be pulled through the conduits and fittings and into the transmitter housing through a conduit seal similar to that shown in Figure 4.2.5.2.4a and secured to the instrument termination screws.

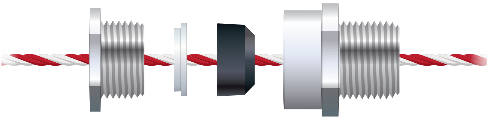


Figure 4.2.5.2.4a – Typical Conduit Seal

There are also poured seals and seals with drains that may be appropriate for some applications. See Figure 4.2.5.2.4b.

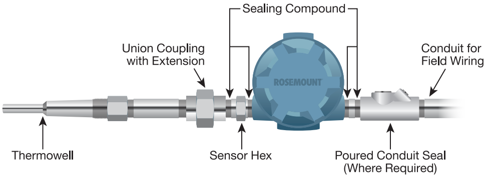


Figure 4.2.5.2.4b – Typical Mounting with Drain Seal

There are specific mounting recommendations for both North American and European accepted best practices as shown in Figure 4.2.5.2.4c and Figure 4.2.5.2.4d.

Consult the Loop Diagram or the transmitter user manual for wiring termination designation. Appropriate tagging of all conductors should be attached.

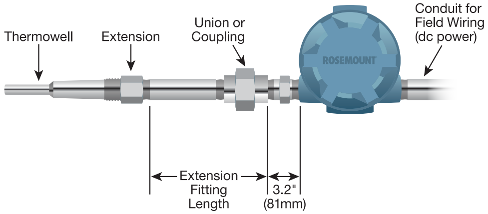


Figure 4.2.5.2.4c – Typical North American Mounting

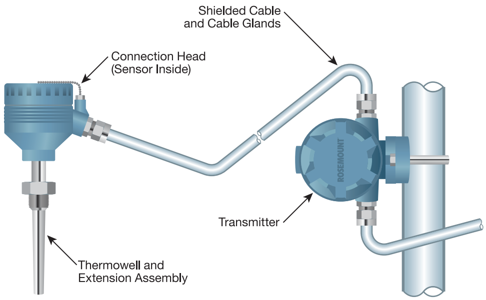


Figure 4.2.5.2.4d – Typical European Mounting

4.2.5.2.4.1 Grounding - Shielding

Each process facility has their own guidelines for the proper installation of grounds and shields. These guidelines should be followed where practical and appropriate. However, if it is desirable to verify that these guidelines are appropriate for your installation or if in doubt about how to proceed, the guidelines below should be followed. See Figure 4.2.5.2.4.1a

Option #1 Remote mount with 2 separate grounding points

- Connect the sensor shield, if supplied, only at the remount mount head and ensure that it is not connected at any other point and is electrically isolated from any grounded equipment.
- Ground signal wiring shield only at the power supply end to an instrument system grounding point and ensure that the transmitter end is carefully isolated
- See Figure 4.2.5.2.4.1a

WHAT ARE THE RECOMMENDED GROUNDING BEST PRACTICES?

Each process facility has their own guidelines for the proper installation of grounds and shields. These guidelines should be followed where practical and appropriate. However, it is desirable to verify that these guidelines are appropriate for your installation or if in doubt about how to proceed.

Refer to:

4.2.5.2.4.1 – Grounding - Shielding

3.1.2.2 – Isolation

Tip: Instrument system ground should not be connected to power wiring ground which can carry noise, surges and spikes that could interfere with measurement signals and/or destroy transmitters. Instrument system ground must be a very low resistance path to an earth grounding rod or grid.

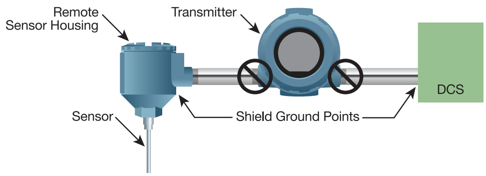


Figure 4.2.5.2.4.1a – Option #1 for Shield Grounding

Option #2 Remount mount with a continuous shield

- Connect the sensor shield only to the signal cable shield and ensure that it is electrically isolated from the transmitter and all other field equipment
- Connect the signal cable shield to instrument system ground only at the power supply end
- See Figure 4.2.5.2.4.1b

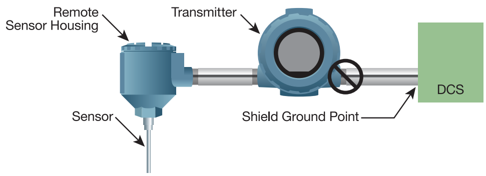


Figure 4.2.5.2.4.1b – Option #2 for Shield Grounding

Option #3 Integral mount

- Ground the signal wiring shield at the power supply end only to instrument system ground ensuring that it is electrically isolated from the transmitter housing and all other field equipment
- This is used for integral mount installations
- See Figure 4.2.5.2.4.1c

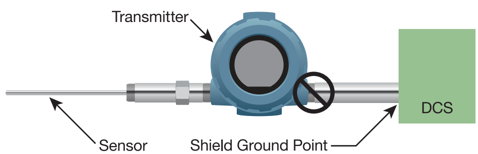


Figure 4.2.5.2.4.1c – Option #3 for Shield Grounding

4.2.5.2.5 Commissioning

Commissioning has been referred to over the years as “ringing out the system” or ‘loop checking the system”. Whatever it may be referred to as in your facility the task is the same. It includes verifying every connection of every loop is properly secured, tagged and connected at both the field and control room ends. It further includes an operational check of each loop to verify that all settings are properly set and that the functionality of the design has been implemented. Extensive use of loop sheets and instrument specification sheets helps to guide this procedure.

For a Safety Instrumented System it is mandatory to completely document this procedure. In other applications complete and proper documentation is considered best practice.

4.2.5.2.6 Acceptance Testing

The acceptance testing procedure is similar to the commissioning procedure but is intended for an official turn-over of a system that is operating according to design specification from the vendor to the owner. For some systems, especially for SIS, this is first conducted at the vendor facility, known as Factory Acceptance Testing or FAT, and then again after installation and commissioning. The terms Site Acceptance Testing (SAT) and Pre-start-up Acceptance Testing (PSAT) are often applied.

4.2.6 Documentation Considerations

A part of the engineering of each temperature measurement system is the development of documents that contain all of the necessary information about the application. These include the Plot Plan, Process Flow Diagram, Piping and Instrument Diagram (P&ID), Installation Details, Instrument Lists, Loop Sheets, and Specification Sheets.

4.2.6.1 – A Plot Plan is an engineering plan drawing or diagram which shows the buildings, utility runs, and equipment layout, the position of roads, and other constructions of an existing or proposed project site at a defined scale. Plot plans are also known more commonly as site plans. See Figure 4.2.6.1a.

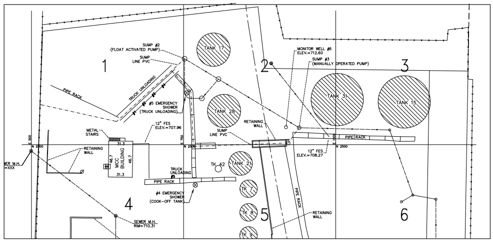


Figure 4.2.6.1a – Typical Plot Plan

4.2.6.2 – The Process Flow Diagram shows the major pieces of equipment in a process area and the design operating conditions. See Figure 4.2.6.2a.

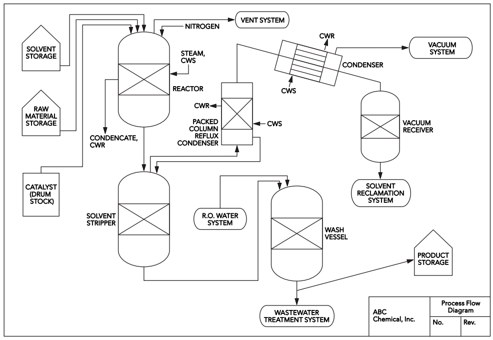


Figure 4.2.6.2a – Typical Process Flow Diagram

4.2.6.3 – Piping and Instrument Diagrams (P&ID) show the anticipated need for measurement and control instrumentation. See Figure 4.2.6.3a.

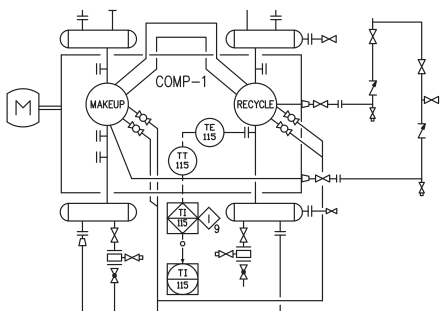


Figure 4.2.6.3a – Example of a P&ID

The P&ID does not indicate precisely where to install the sensors and transmitters, leaving a great deal of latitude in the selection and placement of the specific components by the engineering staff and piping designer. The P&IDs are to be used to describe the relationships between equipment and instrumentation as well as other relevant information that will enhance clarity. Computer software programs that do P&IDs or other diagrams useful to the information package may be used to help meet this requirement. Decisions regarding the use of specific components are often influenced by corporate standards, local preferences, and the existing infrastructure. For temperature loops, P&IDs will show such things as temperature sensing elements (TE), thermowells (TW), temperature indicating transmitters (TIT), temperature indicators (TI), and temperature indicating controllers (TIC). Figure 4.2.6.3b shows typical loop sheet ISA symbols for both an integrally mounted transmitter and a remote mounted transmitter.

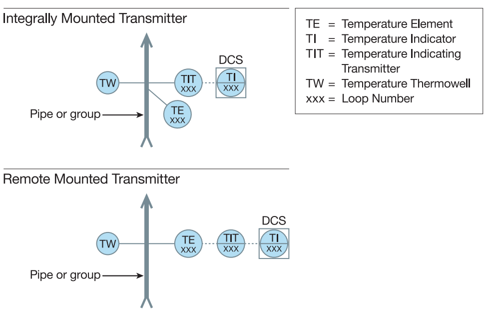


Figure 4.2.6.3b – Typical ISA Symbols for a Temperature Loop

The information pertaining to process equipment design must be documented. In other words, what codes and standards were relied on to establish good engineering practice? These codes and standards are published by such organizations as the American Society of Mechanical Engineers, the American Petroleum Institute, American National Standards Institute, National Fire Protection Association, American Society for Testing and Materials, The National Board of Boiler and Pressure Vessel Inspectors, National Association of Corrosion Engineers, American Society of Exchange Manufacturers Association, and Model Building Code groups.

For existing equipment designed and constructed many years ago in accordance with the codes and standards available at that time and no longer in general use today, the employer must document which codes and standards were used and that the design and construction along with the testing, inspection, and operation are still suitable for the intended use. Where the process technology requires a design that departs from the applicable codes and standards, the employer must document that the design and construction are suitable for the intended purpose.

4.2.6.4 – The Installation Detail Drawing tells contractors and pipefitters the location of each measurement point and how the components are to be installed. This construction document evolves from many decisions regarding thermowells, sensor elements, connection heads, transmitters, etc. See Figure 4.2.6.4a.

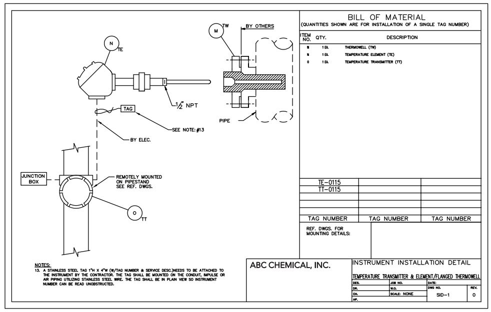


Figure 4.2.6.4a – Installation Detail Drawing

4.2.6.5 – Loop Sheets are developed in some cases, with detailed wiring schematics for the sensors, junction boxes, transmitters, power supplies, and marshalling points reflecting the system architecture. Every loop is numbered, and every sensor and device in the field is tagged. It is an engineering function to create these diagrams, which are cross-referenced with Instrument Lists, so that the system installers know where every single wire is terminated and how every device is grounded. As part of commissioning and before the system can be started and run, the engineers and technicians verify that the wires are installed correctly and that the loops are functioning. See Figure 4.2.6.5a.

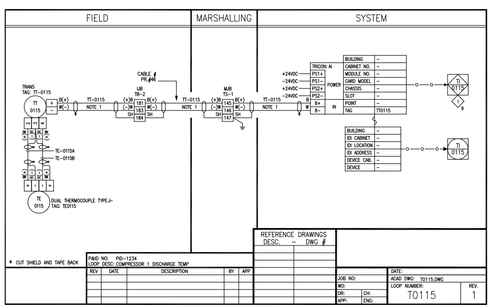


Figure 4.2.6.5a – Typical Loop Sheet

Sensor Type	Sensor Model #	Sensor Mfgr	Sensor Tag #	Transmitter Model #	Transmitter Mfgr	Transmitter Tag #	Service	P&ID Location
RTD	0078N21A30A075T22E5	Rosemount	TE 1234	3144PD1A1E5M5C8C2	Rosemount	TIT 1234	Fractionation	H-17

Figure 4.2.6.6a – Typical Instrument List

4.2.6.6 – Instrument Lists document every instrument comprising the input/output loops, and there can be hundreds of such loops in one automated process. Columns show the type of sensor its model number and manufacturer, the service, the transmitter type model number and manufacturer, the tag name/number for each device, and the location on the P&ID. See Figure 4.2.6.6a It may also include I/O detail information showing where every input is terminated by rack, card, and terminal, with the same detail for every output.

4.2.6.7 – ISA standard Specification Sheets are the basis for ordering instruments, so they must contain all the dimensions and other information needed by a manufacturer to configure each component to function according to the design and the demands of the process. Specification Sheets are generally kept on file in the plant along with P&IDs as reference documents. See Figure 4.2.6.7a.

ABC CHEMICAL, INC.

THERMOCOUPLES / THERMOWELLS — SHT 1 OF 1

NO	BY	DATE	REVISION	SPEC. NO	REV.
				CONTRACT	DATE
				BY / CHK	APPR

1. Complete Assembly [X] Other ____
   MFR. & Model No. 0183D22J2C60A110F96E5Q8R06R21

ELEMENT

MFR. & Model No. ____

2. ISA Type Type J Wire Size 18 AWG
3. Sheathed: 3/8 " O.D. Material 316 SS
   Exposed [ ] Grounded [X] Ungrounded [ ]
   Enclosed [ ] Beaded Insulators [ ] Spring Loaded [X]
4. Nipple Size ____ Dimension "N" 6 " Union [X]
5. Packed Connecter ____

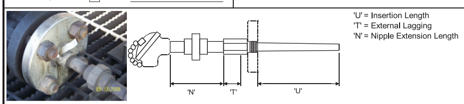
HEAD

6. Screw-Cap & Chain [X] Other ____
7. Material EXPL PRF ALUM Conduit Conn. 1/2" FNPT
8. Terminal Block: Single [ ] Duplex [X]

WELL OR TUBE

9. Material: N/A
10. Construction: Tapered [ ] Straight [ ]
    Drilled [ ] Built-Up [ ] Closed End Tube [ ]
11. Dim: Mfg Std [ ] O.D. ____ I.D. ____
12. Connections: Process FLANGED Int ____
13. Other Specs.: 1-1/2" 600 AL82 F304

Notes: S/N 1240442



Rev	Tag No.	P&ID	Service	TW Dimensions 'U'	TW Dimensions 'T'	Process Connection	Notes
1	TE-0115	PID-1234	Compressor 1 Discharge Temperature	11"	0 "	1.5" 600#	1,2,3

Notes
1. Vendor to permanently attach a 316SS tag to each instrument containing Tag No., Service, and PO No.
2. T/C element shall be mineral insulated with 0.375 " O.D. SS sheath.
3. Purchase thermocouple element, thermowell & head.
4. Process Data for thermowell velocity calcs: Discharge temp normal 110 deg F, Discharge press normal 880 psig Discharge flowrate 17 mmscfd, Molecular weight 84 (76 min, 89 max), Pipe size? 11-12 inch

Figure 4.2.6.7a – ISA Temperature Transmitter Specification Sheet

WHAT IS THE BENEFIT OF TRANSMITTER-SENSOR MATCHING?

Temperature sensor-transmitter assemblies can be visualized as "good-better-best" where a transmitter used with a Class B sensor is "good"; a transmitter used with a Class A sensor is "better" and a transmitter matched to a sensor using the CVD constants method is "best".

Refer to:

Figure 3.2.3.12b – Good-Better-Best: Calibration Comparison of Systems Using a Class B Sensor vs. Using a Class A Sensor vs. Using the CVD Method

3.1.4.3.3 – Transmitter-Sensor Matching

4.2.7 – System Error Analysis, with Example TPE Calculations

4.2.7 System Error Analysis

As discussed in the Temperature Measurement Basics chapter 3 Section 3.1.4.2, Worst Case Error (WCE) is the largest possible error expected under the anticipated conditions. A more realistic measure is the Total Probable Error (TPE) which is a root sum of the squares of multiple error producing factors affecting the accuracy.

Two calculations are presented that contrast the TPE of a basic transmitter using a standard Class B sensor against a high accuracy transmitter matched with a Class A sensor using the Callendar van Dusen constants of the sensor. For precision applications the results clearly show the benefit of sensor-transmitter matching.

Example 1: Low Accuracy TPE Calculation

The conditions:

- Basic accuracy transmitter
- Class B RTD sensor
- Ambient temperature change: 20 - 40 °C
- Process temperature range: 40 - 400 °C
- Reference temperature is 20 °C

Digital Accuracy: ±0.150 °C for a PT 100 (alpha .00385) RTD sensor

D/A Accuracy = ±0.030% of transmitter span
= 0.030% x (400-40) °C
= 0.108 °C

Digital Temp Effects = 0.003 °C per 1.0 °C change in ambient temperature
= 0.003 x (40-20) °C
= 0.060°C

D/A Effect = 0.001% of span per 1.0 °C change in ambient temperature
= 0.00001 x (400-40) °C x (40-20) °C
= 0.072 °C

Sensor accuracy = ±2.30 °C @ 400 °C for a class B RTD sensor

TPE $= \sqrt{DigitalAccuracy^2 + D/AAccuracy^2 + DigitalTempEffects^2 + D/AEffects^2 + SensorAccuracy^2}$
= √ 0.1502 + 0.1082 + 0.0602 + 0.0722 + 2.3002
= ± 2.309 °C

Example 2: High Accuracy TPE Calculation

The conditions:

- High accuracy transmitter
- Class A RTD sensor with CVD constants
- Ambient temperature change: 20 - 40 °C
- Process temperature range: 40 - 400 °C
- Reference temperature is 20 °C

Digital Accuracy = ±0.100 °C for a PT 100 (alpha .00385) RTD sensor

D/A Accuracy = ±0.020% of transmitter span
= 0.020% x (400-40) °C
= 0.072 °C

Digital Temp Effects = 0.0015 °C per 1.0 °C change in ambient temperature
= 0.0015 x (40-20) °C
= 0.030 °C

D/A Effect = 0.001% of span per 1.0 °C change in ambient temperature
= 0.00001 x (400-40) °C x (40-20) °C
= 0.072 °C

Sensor accuracy = ±0.420 °C @ 400 °C for a class A RTD sensor with CVD constants

TPE $= \sqrt{DigitalAccuracy^2 + D/AAccuracy^2 + DigitalTempEffects^2 + D/AEffects^2 + SensorAccuracy^2}$
= √ 0.1002 + 0.0722 + 0.0302 + 0.0722 + 0.4202
= ± 0.445 °C

For the most critical of applications a more in-depth analysis of the overall temperature measurement system accuracy includes consideration not only of the sensor and transmitter accuracy specifications but also a variety of other factors including T/C junction degradation, sensor insulation deterioration, sensor cycling drift, flow rate variations, heat conduction losses, etc. Since many of these are difficult or impractical to measure, good engineering judgment should be applied starting with the selection of a high quality sensor-transmitter system and then adding a margin of error allowance. For example, instead of operating using standard calibration procedures opt for sensor-transmitter matching to increase the system accuracy by about a factor of four.

4.2.8 Durability and Reliability – The Confidence Factor

Selecting a temperature measurement system with a proven track record of reliability is valuable to process confidence. A system with documented results from long term operation and proof testing will ensure confidence. If a problem is suspected with the process system, time is often wasted troubleshooting the source of the issue. If a particular sensor is determined to be the cause or a contributor to the issue, the sensor will need to be recalibrated or replaced. Replacement often requires shutting down the process causing unplanned and expensive production downtime. Product quality issues or even product loss can occur when a process control loop is operating inconsistently or inaccurately.
If the solution is frequent replacement of a lower quality sensor, additional and often hidden costs are incurred including additional spares inventory with related purchasing and stocking costs. Added to that overhead cost is the cost of recalibration services and process verification procedures. These costs are very real yet often are hidden and difficult to capture and measure.

It is important to match the sensor accuracy with the requirements of the process. General good practice would suggest that the sensor accuracy should be about 4 times better than the measurement accuracy required by the process. The value of this approach relates not only to process control confidence but also energy savings. For energy intensive processes, wasted thermal energy can add a significant amount of cost over time. For example, just a one degree error in control of a small heat exchanger could easily cost over $10,000 per year in wasted energy.

4.2.9 Guidance Review for Ensuring Optimal System Performance and Accuracy

Throughout this handbook guidance has been offered for ensuring the best accuracy and performance of your temperature measurement system including:

- Use a 4 wire spring loaded RTD unless the measured range exceeds 850 °C
- Integrally mount the sensor with the transmitter whenever possible to minimize noise pickup
- Use a transmitter in a dual compartment housing to minimize environmental influence on the transmitter
- Use a stepped well for fastest response
- Perform a wake frequency analysis to ensure selection of a proper thermowell configuration that will withstand the vibration caused by vortex shedding from the well
- Specify sensor-transmitter matching for best accuracy
- Consider use of dual element sensors for redundancy and drift monitoring
- For installations in electrically noisy environments, specify transient suppression
- Consider specifying intelligent filtering options as they may be appropriate See section 6.0 in the Transmitter chapter for a detailed description

Tip: Proceed to Chapter 4.3, Connecting to Your Control System for further guidance.

4.3 Connecting to the Control System

4.3.1 Overview

To be useful for control, monitoring or logging of the measured temperature, the signal must be communicated from the field measurement site to the control room. Many plant sites have established preferences on how this is accomplished most commonly using field mounted transmitters or direct wiring from the field to control room device input cards. Each method has its proponents but the following discussion will make the case for a strong preference for using transmitters over using direct wiring.

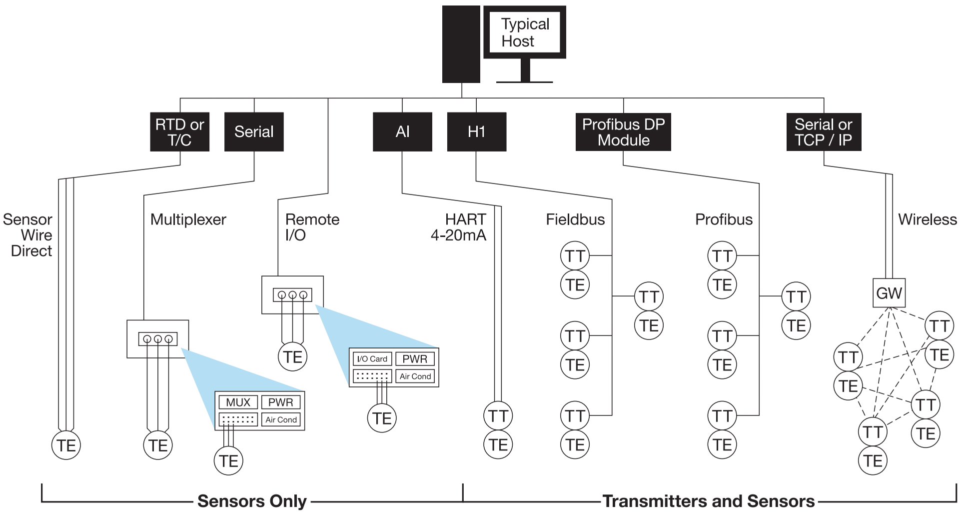


Figure 4.3.1a

In the following sections each available technology is discussed in detail.

A system diagram illustrating all technologies is in Figure 4.3.1a.

Pros and Cons of these technologies are compared in Figure 4.3.1b.

Technology	Pros and Cons
Wire Sensors Directly to DCS	• High Wiring and Infrastructure Cost • Prone to Interference • High Maintenance • Limited Feature Functionality and Performance vs. Transmitter
Multiplexors	• Dated Technology • Slow Updates • Reliability Issues • Limited Accuracy and Performance Specifications • Area Certification and Environmental Limitations • Limited Parts, Service
Control System Remote I/O Racks	• Good Basic Capability • Proprietary Infrastructure • Limited Feature Functionality and Performance vs. Transmitter • Area Certification and Environmental Limitations
Transmitters and Sensors	• Highest Accuracy • Excellent Noise Immunity • Lowest Cost of Ownership • Wide Choice of Measurement Enhancement Features

Figure 4.3.1b – System I/O Option Comparison

4.3.2 Transmitters

The transmitter converts the measurement input signal from RTDs, T/Cs, mV or resistance sensors to highly robust analog or digital signals for communicating with the host.

Transmitters are available in a variety of housing styles that may be mounted into any of a wide selection of enclosures that are available in many different materials of construction. They may be mounted integrally with a sensor / thermowell assembly at the process measurement point and transmit either a hard-wired or wireless signal. Alternatively, they can be mounted remotely from the sensor assembly in any of several types of enclosures. They can be configured locally or remotely and can provide local indication. They have an array of standard and optional performance features to provide remarkable functionality. Systems may be provided to meet virtually any agency approval requirement.

A smart transmitter generally provides a more accurate and robust temperature measurement than is provided by direct wired I/O systems. A smart transmitter provides signal isolation, filtering, linearization and sensor type or sensor specific compensation to the measurement before sending the value to the host system.

TIP: Refer to the Temperature Measurement Basics, Section 3.1 for a detailed discussion.

4.3.2.1 Output Signals

After the signal conditioning functions as described above are completed, the measurement is converted to a highly accurate analog or digital signal with excellent noise immunity as compared to the weaker and noise susceptible signals coming directly from the sensor.

4.3.2.1.1 Analog Current:

Industry standard 4-20 mA analog signals are used globally to communicate with field mounted devices over long distances.

4.3.2.1.2 HART®

The HART (Highway Addressable Remote Transducer) protocol is a hybrid protocol that provides for a digital signal superimposed onto the 4-20 mA signal. The protocol also has a provision for all digital multi-drop communication.

4.3.2.1.3 FOUNDATION™ Fieldbus

Foundation Fieldbus is an all-digital, serial, deterministic peer-to-peer communications protocol that serves as a field-based device network in a plant or factory automation environment.

4.3.2.1.4 PROFIBUS

PROFIBUS PA is an all-digital master/slave communications protocol that serves as a field based device network in a plant or factory automation environment

4.3.2.1.5 WirelessHART™

WirelessHART™ is an open-standard wireless self-organizing mesh network based wireless communication protocol developed to complement the existing HART protocol.

4.3.3 Direct Wiring

Direct wiring terminates the temperature sensors directly to control or monitoring system input cards where it is converted into a digital value of the temperature measurement for use in that system. These control room systems could be a DCS, PLC, data logger, or controller.

For RTD sensors standard copper extension wire is used for all four leads. However, for thermocouple sensors, specially matched extension wire must be used or huge measurement errors will result.

4.3.3.1 Control System I/O

Field wiring may have each sensor cable run all the way to the control room in cable trays or conduits terminating at I/O cards in a rack room or control room. Care must be taken to separate and isolate the low level signal wiring from any higher voltage wiring to reduce EMI and RFI noise interference. Minimum separation distance is dependent on several factors including voltage levels, current levels of switched signals, digital signal level, etc. and if they are shielded and properly grounded. Some facilities use separate trays for high level signals and others suggest separation distances ranging from 150 to 600mm (5.9 to 23.6 in). All signal conditioning takes place in the input card.

4.3.3.2 Remote I/O

Another alternative is using field mounted I/O subsystem mounted into I/O cabinets. This subsystem uses a digital communication link to connect to control room systems. These com links may be Ethernet, vendor proprietary, or a fieldbus protocol which must also be separated and isolated from high voltage wiring. This approach can be cost effective for high density measurement applications where the higher accuracy and performance of a transmitter is not required. While this design reduces the length of sensor extension wire it does have other limitations and requirements. Operating power must be supplied to the cabinet which may limit access to the I/O without a hot work permit. There are also environmental concerns and limitations that may require purged cabinets. Environmental conditioning such as heating and air conditioning may be required as control system I/O generally has more restrictive limits for operating temperature, humidity, corrosion, and other environmental factors. Explosion proof certification is impractical.

WHY SHOULD LONG SENSOR WIRES BE AVOIDED AND WHAT ARE THE ALTERNATIVES?

The cost of ownership of sensor extension wire far exceeds the cost for standard two-wire cable typically used for transmitter output signals. Just for this reason alone mounting the transmitter as close as is practical to the sensor will be cost effective.

From a performance point-of-view, long leads act as an antenna for electrical noise that will always be present in a plant environment where there will be electrical interference sources like pumps, motors, Variable Frequency Drives (VFD's) and radios as well as sources of electrostatic discharge and other electrical transients. Low level sensor signals from RTDs and T/Cs are very susceptible to this noise potentially causing very large errors in the measurement. The longer the leads (The antenna) the greater will be the noise pickup.

The best alternative to this problem is to use a transmitter that is designed to reject common mode and normal mode interference as well as provide a high degree of immunity to EMI, ESD and RFI. Where possible and practical, transmitters should be mounted close to the measurement point to minimize potential noise pickup by the sensor leads. This is especially important for low level T/C signals which are especially susceptible to noise.

Refer to:

3.1.2.4.1 – Noise filtering

4.3.4 – Advantages of Using Transmitters vs. Direct Wiring

4.3.3.3 Multiplexers

Multiplexers communicate with the control system using either a serial transmission (RS232C or RS485) or Ethernet. The communications may utilize a proprietary protocol provided by the control system manufacturer or one of the other standard protocols such as Modbus, OPC, or Profibus. This is a dated technology that has serious reliability issues and that has decreasing usage in the process industries.

4.3.4 Advantages of Using Transmitters vs. Direct Wiring

Cost of installation and ownership of using a transmitter approach vs. direct wiring shows a clear advantage to the transmitter for most applications

- Specifying a single temperature transmitter, sensor, and thermowell assembly to meet a specific performance goal places all the responsibility on a single vendor and saves multiple specification sheets, quotation requests, bid reviews and purchase orders
- Drafting costs are lower with only a transmitter symbol to show for a field device and only copper wire to show on the P&ID and bill of material. Drafting costs can be further reduced using multi-point temperature transmitters on digital bus applications.
- Wiring between the transmitter and the control system is done using standard copper wires in shielded, twisted pairs. This is far less expensive than multiple types of T/C extension wire or 4-wire RTD extension cable. Note that 4-wire RTDs are highly recommended vs. 3-wire systems
- Less wiring infrastructure is needed in transmitter based systems for RTD installations. Two wires instead of four save wiring which can be used for other measurement needs. Two wire solutions also save on overall wiring infrastructure including junction boxers, cable, conduit, cable trays, and the physical infrastructure to support and route all the wiring.
- The requirement for using different types of T/C extension wire often leads to wiring errors at installation. This problem is eliminated by having all copper for the field wiring
- All transmitters can be the same manufacturer and model minimizing spares
- Only one type of high level input card is required for the control system instead of a mixture of high level and low level cards. Low level sensor input cards are typically more expensive than 4-20 mA input cards and spares inventory is reduced
- No need to periodically replace degraded T/C extension wire. Copper wire typically lasts for the life of the plant.

- Higher performance is assured since a transmitter-sensor assembly may be calibrated as a system for optimal accuracy which cannot be done with a direct wired system and sensor-transmitter matching may also be performed
- Trouble shooting and maintenance time is reduced by utilizing transmitter diagnostics that are not available or are quite limited in input cards
- Transmitter accuracy and performance is typically twice as good as direct wired temperature inputs.
- The robust transmitter output signal is far less susceptible to EMI and RFI interference than low level sensor signals where the extension cables act as antennas for the noise signals
- Transmitters offer a local indication option which improves operator interface and reduces maintenance time
- Intelligent filtering options, common in transmitters, must be done in system software (if at all) in the DCS
- For T/C applications, accuracy deterioration due to extension wire degradation can be severe
- Safety related applications are by far best done in a transmitter system. In SIS an error in excess of 2% is considered an undiagnosed dangerous failure
- Sensor types can be changed from T/C to RTD or to a different type of T/C or RTD and the same transmitter is easily reconfigured to the new sensor type. The output cable and the DCS input card stay the same. For direct wiring extension cable would likely need to be changed as well as the DCS input card type.

4.3.5 Advantages of Direct Wiring Strategy

- May be lower initial cost. This is highly dependent on the cable distances involved, the cost of the cable and installation costs, and available wiring infrastructure

4.3.6 Grounding and Shielding Considerations

In general, established facility policies and guidelines should be followed where appropriate. See 4.2.5.2.4.1, Grounding-Shielding.

4.3.7 Loop Load Insights

The majority of field measurement 4-20 mA signals are connected to a single input on a control or monitoring system. However, there are some occasions when connecting two or more devices in series is required.

Typically, for a 24 VDC power supply and a transmitter requirement of 12 VDC, 12 Volts remain to drive the load. If we allow for a maximum loop current of 24 mA, the maximum load is 500 Ω. (12 V ÷ 24 mA.) Since the load of most input circuits in control systems is 250 Ω, one transmitter could drive two receiving channels in a series connection.

Increasing the power supply voltage to 42 VDC (The maximum voltage allowed for field devices is 42.4.) would allow a maximum load of 1250 Ω. See Figure 4.3.8a.

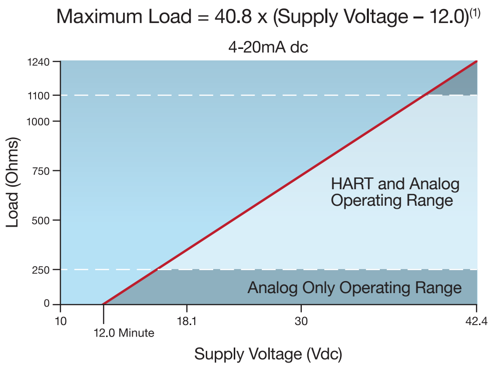


Figure 4.3.8a – Loop Loading

5

Maintenance and Calibration

TOPIC PAGE

5.0 Overview

Maintenance policies and procedures have evolved over the decades as instrumentation has evolved. Older transmitters using analog circuitry required maintenance much more frequently than do today's microprocessor-based transmitters. The analog devices had multiple potentiometers to adjust for various drifting or offset conditions and were repairable at the board level while microprocessor-based units have almost negligible drift and are not unlike our cell phones, TVs and laptop computers that have "no user-repairable parts".

Similarly, sensor technology has matured over the years with better manufacturing methods that tend to reduce long term drift and failure rates. However, sensor drift, degradation and failure are still the driving factor of temperature system maintenance scheduling. High quality RTDs can be expected to have minimal acceptable drift up to 5 years or even longer depending on the application. However, thermocouples inherently begin drifting to some extent from the beginning. This junction degradation-caused drifting is exacerbated by adverse operating conditions. In applications where errors of a few degrees are acceptable, the life may be several years and for other more demanding applications the drift can be several percent per year necessitating more frequent maintenance. Additionally, the special leadwire extension cable that must be used for thermocouples also degrades over time and must be replaced on a regular basis.

Proper maintenance planning should be done at the beginning of the lifecycle of the installation. Scheduling will vary dramatically depending on the application and the operating and environmental conditions. Clearly a critical measurement with serious consequences for inaccuracy or failure will have a higher priority than a simple monitoring or non-critical control measurement loop. There must be a balance struck between the lower costs of long maintenance intervals with the potential of consequences from measurement errors and the higher costs of shorter intervals. Maintenance costs include not only manpower but also costs associated with taking a loop out of service for the maintenance duration. Some loops will operate just fine in manual while others could precipitate process upsets if placed in manual and may necessitate a process shutdown.

Unfortunately, calibration has costs associated with it and in uncertain economic times, this activity can often become neglected or the interval between calibration checks on instruments can be extended in order to cut costs or simply through a lack of resources or manpower. However, neglecting calibration can lead to unscheduled production or machine downtime, product and process quality issues or even product recalls and rework.

Furthermore, if the instrument is critical to a process or is located in a hazardous area, allowing that sensor to drift over time could potentially result in risk to employee safety. Similarly, an end product manufactured by a plant with poorly calibrated instruments could present a risk to both consumers and customers. In certain situations, this may even lead to a company losing its license to operate due to the company not meeting its regulatory requirements. This is particularly true for the food and beverage sector and for pharmaceutical manufacturers where there are very specific requirements for documented calibration.

Calibration also ensures that product or batch quality remains high and consistent over time. Quality systems such as ISO 9001, ISO 9002 and ISO 14001 require systematic, well-documented calibrations with respect to accuracy, repeatability, uncertainty and confidence levels. This affects all process manufacturers.

In planning a maintenance strategy it is wise to carefully evaluate the benefits of proper calibration intervals of increased throughput, less product waste, reduced energy costs, fewer unscheduled production shutdowns and regulatory compliance against the savings associated with the reduced labor requirements of longer intervals.

5.1 What Qulifications are Required for Maintenance Personnel

Maintenance Technician qualifications will vary from company to company and from plant to plant within the same company. In some companies seasoned veterans of many years of attending the "school of hard knocks" possess invaluable experience for troubleshooting and maintenance. In many cases however, young "unseasoned" techs are thrust into the maintenance responsibility. For these people it is strongly suggested that they be encouraged (required?) to attend courses to obtain a Certified Control System Technician (CCST) accreditation. ISA is very strong in providing such courses. (www.isa.org) There are also courses available through community colleges and other commercially taught programs as well as apprenticeships and mentoring opportunities.

Since potential errors in calibration or other maintenance procedures can have expensive and even dangerous consequences, the technician must demonstrate a high degree of honesty and integrity, keen attention to detail and excellent documentation practices. 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.

Proper training and experience should be a requirement for control system technicians.

5.2 What is Included in a Maintenance Program

Although maintenance by definition is concerned with maintaining something that exists, many plants rightfully get the maintenance technicians involved early on in the design phases to offer opinions that help to make equipment selection decisions based on user experience. Further they may participate in commissioning and acceptance testing to help verify that a properly working system exists at start-up for which they will then have the responsibility for keeping it operating that way throughout the life of the installation.

Tasks and responsibilities that typically fall under the maintenance department include:

- Participating in Site Acceptance Testing (SAT)
- Participating in commissioning and start-up procedures
- Maintenance scheduling and planning
- Physical inspection of field devices to verify physical and electrical integrity
- Routine analysis of diagnostic information
- Routine calibration or recalibration of sensors and instruments
- Loop Tests
- Configuration verification and/or changes
- Troubleshooting and resolving abnormal performance issues
- Installation and commissioning of replacement or expansion equipment
- Documentation of all stages and facets of any procedure
- Continuing education and training
- Cross training with co-workers

5.3 Maintenance scheduling and Planning Considerations

As was mentioned in the introduction, there needs to be a balance between too little and too much. To make this determination requires a thorough understanding of each measurement loop considering such things as:

- What measurement precision is required and with what tolerance for drift
  - Critical loops with serious consequences for errors always have a higher priority than other loops
- The drift aspects and expectations of the system sensor
  - RTD loops are typically more stable than T/C loops and would have a longer interval between calibrations
  - Control loops usually have higher priority than monitoring loops
- Any adverse operating conditions associated with the measurement installation that could accelerate drift requiring more frequent maintenance
  - High temperature, vibration, and corrosive environment can all accelerate drift
- What is involved to take each loop out of service for calibration / repair
  - What permits and permissions are required to work on the loop
  - Can the loop be bypassed / placed in manual
  - Is advance notice to operations required
  - Is any special equipment necessary and available
  - Are equipment lock-outs and tagging involved (LOTO)
  - Are there safety issues involved
  - Is transmitter in hazardous area
- Can the calibration be done in situ or does the transmitter and/or sensor need to be brought to the shop

- Availability of any spares that may be needed for the maintenance procedure
- Is the measurement a safety instrumented function that is part of an SIS
  - Safety related instrument loops are typically tested according to a very specific and detailed procedure in a SIS Test Plan for a unit operation
  - If redundancy is involved as in dual sensors, 1 out of 2 (1oo2) or 2 out of 3 (2oo3) transmitter voting, the test plan will have very specific methodology that must be carefully followed and properly documented
  - See SIS section below and in Chapter 8.3 for further insights
- Evaluation of multiple before and after calibration results over time to adjust calibration scheduling
  - For critical loops perform calibration checks often at first (like once per month) for several months to get statistical data and then continue to extend interval to a time period where results are just at the edge of their allowable range
  - Loops with similar time schedules should then be grouped together
  - Consideration of process shutdown schedules
  - This process is greatly facilitated by using a calibration management software entity and/or an asset management system
- Coordination with any outside contractors that may be involved

Tip: Many of the considerations listed above may be implemented in an asset management system linked to a calibration suite of software and documenting calibrators. The benefits include faster and more accurate calibrations, improved scheduling and documentation. See Maintenance Management Section 5.4 for more detail.

5.4 Maintenance Management

Historically many companies performed maintenance on as-needed basis. Many followed the old adage that *"if it is not broken, don't fix it"*. However, today's modern process plants, production processes and quality systems, put new and much tighter requirements on the accuracy of process instruments and on process control.

Quality systems, such as the ISO9000 and ISO14000 series of quality standards, call for systematic and well-documented calibrations, with regard to accuracy, repeatability, uncertainty, confidence levels etc. In today's world there are techniques and calibrations systems that greatly facilitate meeting these calibration requirements.

The limiting factor in most processes is the quality of the measurements provided to the control system. Optimization of any process makes decisions based on the information provided. Inaccurate information will lead to less than optimal system performance. The more critical the process the more important accurate and stable measurements become. Examples can include energy management, custody transfer, pharmaceutical production, and fractionation optimization.

All measurement instruments will drift over time. The only questions are how much will they drift and what amount is acceptable for that particular measurement. The pharmaceutical industry in the USA and for any company manufacturing for sale in the USA is particularly stringent about calibration procedures, test equipment, and documentation. Detailed requirements may be found in FDA regulation 21 CFR Part 11.

Maintenance Management Software Systems can greatly facilitate plant instrumentation maintenance programs. *See Figure 5.4a.*

Choosing professional tools for maintaining calibration records and doing the calibrations can save a lot of time, effort and money.

A basic calibration management system consists of calibration management software and documenting calibrators.

Figure 5.4a – Documenting Calibrator and Calibration Management Software (Courtesy of Beamex)

Modern calibration management software can be a tool that automates and simplifies calibration work at all levels. It automatically creates a list of instruments waiting to be calibrated in the near future. If the software is able to interface with other systems like an asset management system with a device manager capability the scheduling of calibrations can be done in the maintenance system from which the work orders can be automatically loaded into the calibration management software.

When the technician is about to calibrate an instrument, they simply download the instrument details from the calibration management software into the memory of a documenting calibrator; no printed notes, etc. are needed. The "As Found" and "As Left" are saved in the calibrator's memory, eliminating the need for manual documentation with its associated potential for error.

The instrument's measurement ranges and error limits are defined in the software and also downloaded to the calibrator. Thus the calibrator is able to detect if the calibration was passed or failed immediately after the last calibration point is recorded. There is no need to make tedious calculations manually in the field.

All this saves an extensive amount of time and prevents the user from making mistakes. The increase in work productivity using such a system allows for more calibrations to be carried out within the same period of time.

While the calibration results are uploaded onto the database, the software automatically detects the calibrator that was used, and the traceability chain is documented without requiring any further actions from the user.

Calibration records, including the full calibration history of an instrument, are kept in the database; therefore accessing previous results is also possible in just a few seconds. When an instrument has been calibrated several times, software displays the "History Trend", which assists in determining whether or not the calibration period should be changed.

One of today's trends is to move towards to a "paperless office". If the calibration management software includes the right tools, it is possible to manage calibration records in a database with minimal paper. If paper copies of certificates are preferred, they may be printed with simple formatting.

Today's documenting calibrators are capable of calibrating a variety of measurement signals and can interface with basic milliamp signals as well as HART, FOUNDATION™ fieldbus and Profibus protocols (Optional on some models). See Figure 5.4b.

These systems provide a great benefit to maintenance managers for planning purposes, QA departments, and outside auditors.

Figure 5.4b – Documenting Multifunction Calibrators (Courtesy of Beamex)

5.4.1 Additional Benefits of Asset Management Systems

Today's widespread use of smart field instruments adds a new dimension to maintenance management. The wealth of operational and diagnostic data resident in smart instruments is extensive. Using HART or fieldbus protocol makes this information readily available. On a very basic level, field configuration tools can access any of this information by request one instrument at a time. If a maintenance technician does nothing else he should review this information on a regular basis to catch performance or failure issues before they can affect the process. However, in most process plants there are manpower and priority issues that typically leave little time for this proactive type of activity no matter how beneficial the practice would be to a better and more efficient maintenance plan.

An alternative solution to accessing this information exists on a higher level where this data can be accessed continuously from all field devices simultaneously using fieldbus or HART-enabled multiplexors interfaced with an asset management system suite. There are even wireless solutions to collect this data. When used with asset management system software suites, all performance and diagnostic data from all field devices can be immediately available. With these tools predictive scenarios can be recognized and action implemented proactively instead of reactively after a problem manifests itself and the process is affected and costs are incurred. See Figure 5.4.1a.

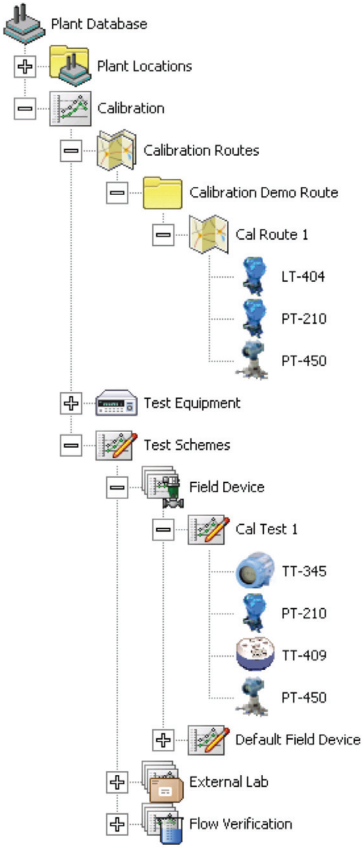


Figure 5.4.1a – Typical asset mangement system Calibration Screen

An asset management system with a device manager capability helps avoid these unnecessary costs with a universal window into the health of intelligent field devices. It provides maintenance and operations personnel the ability to work smarter. Based on real-time condition data from intelligent field devices, plant staff can respond fast and make informed decisions on whether to maintain or replace field devices.

With an asset management system, you can commission and configure instruments and valves, monitor status and alerts, troubleshoot from the control room, perform advanced diagnostics, manage calibration, and automatically document activities with a single application. There is also the ability to interface an asset management system to documenting calibrators as is described above with all of the data required to perform calibration. See Figure 5.4.1b.

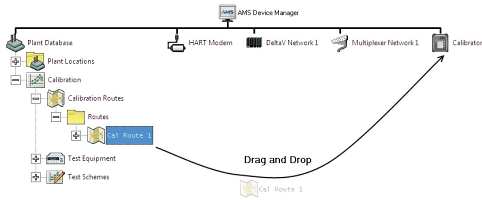


Figure 5.4.1b – Asset mangement system Interface to Documenting Calculator

5.5 Maintenance Basics

5.5.1 Transmitters

- Mechanical inspection/repairs – Inspect for:
  - – Proper installation guidelines followed
  - – Corrosion
  - – Loose mounting
  - – Erosion
  - – Covers are on tight with metal-to-metal seal
  - – Conduit seals are tight
  - – Moisture intrusion
- Electrical inspection/repairs - Inspect for:
  - – Clean and tight terminations
  - – Corrosion on terminals or housing
  - – That the surge suppressor is not damaged
  - – LCD operating properly
  - – The shield and case grounding is correct and intact. Refer to Section 4.2.5.2.4.1 in the Engineering and Design Chapter for grounding detail.
- Additional Considerations for Wireless Devices
  - – Verify that no new equipment or structures have been installed nearby to the wireless transmitter that could affect the wireless signal transmission
    - Must maintain about 1.8 meters minimum (6 ft)
  - – Verify power module voltage / replace if necessary
    - Slower update rates provide longer battery life

5.5.2 Sensors and Thermowells

- Remove sensor from thermowell for calibration or replacement
  – Refer to Calibration section below
- Clean well bore of thermal paste and/or corrosion
- Inspect for corrosion on terminals, enclosures and on thermowell.
- Inspect thermowell mounting for evidence of cracking indicating potential failure
- Inspect and tighten flange bolts
- For high temperature applications verify integrity of protection tube
- For surface mount sensors
  – Verify mounting is secure for good thermal contact of the sensor tip with the process vessel or pipe
  – Verify that the insulation surrounding the sensor is in place with minimal leakage
  – For pipe clamp units ensure clamp bolts are tight and that no corrosion exists

5.6 Configuration

The process of configuration includes the selection and adjustment of a wide assortment of transmitter operating parameters including the most simplistic to the more advanced features. Many of these are factory set to either a default or user specified condition or value. Others are application specific and are field set as part of commissioning of the measurement loop. While some settings are physical procedures on the transmitter (Like switches or jumpers), other of the settings are accessed using a field configurator, a laptop, an asset management system, a DCS or other electronic means. The majority of loops support HART, FOUNDATION™ fieldbus, or Profibus protocols.

Since HART has been in widespread use in the process industry for many years there are millions of the devices installed globally. These devices will likely stay in service and overlap with newer devices using fieldbus protocol. As plants begin to use fieldbus for new operational units or upgrades of older units there will be a requirement for the maintenance technician to have a working familiarity with more than one protocol.

HART and fieldbus devices typically have similar Device Description Languages (DDL) for configuration and diagnostic data contained in them and there are universal field communicators that can access some or all of the devices. *See Figure 5.6a.* Each protocol uses its own specific method to access various menu trees for status, operational data, configuration and diagnostics.

Figure 5.6a – Hand held Field Communicator

5.7 Calibration

5.7.1 Overview and Definition

Calibration is distinctly different from transmitter ranging or adjustment of other transmitter configuration parameters that are normally entered during commissioning. Changes to these values are not typically part of a calibration procedure although some parameters may be authorized by management to be done at that time like adjusting damping or changing an alarm setpoint.

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 (the quantity being measured) 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 instrument against a standard instrument of higher accuracy to detect, correlate, adjust, rectify and document the accuracy of the instrument being compared.

Another source defines calibration as including the process of adjusting the output or indication on a measurement instrument to agree with the value of the applied standard, within a specified accuracy. As an example for a temperature transmitter, a known input is applied and the output adjusted so that the output as seen by the user is within a given tolerance of the actual value of the applied standard.

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 that were configured into the unit at commissioning.

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. As an example, a temperature transmitter with an RTD input has a potential range of -200 to 850 °C to produce a 4-20 mA output. However, for a specific application it is to be calibrated to a range of 0 to 50 °C for 4-20 mA output. For this example the input zero value is 0 °C and the input span is 50 °C and the output zero value is 4 mA 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.

5.7.2 When to Calibrate

Calibration is performed for one or more of the following reasons:

- During commissioning of a new instrument
- After a transmitter has been repaired or modified
- When a specified time period has elapsed
- When a specified usage such as operating hours has elapsed
- Before and/or after a critical measurement

WHAT ARE BEST PRACTICES FOR CALIBRATION?

Every industrial facility will have policies, procedures, and guidelines concerning calibration. Some may be well founded and based on years of experience and others may follow the “We have always done it this way” mentality wheather it is right or wrong.

Here are some insights and recommendations. Refer to:

5.7.2 – “When to calibrate”
5.7.3 – “Understanding the terms”
5.7.5 – Equipment
5.7.5.1 – Procedures
5.8 – High-Precision considerations

- After an event has occurred that may have put it out of calibration or damaged it like shock, vibration, exposure to an adverse condition like a lightning strike, or sudden changes in weather
- Whenever observations appear questionable or instrument indications do not match the output of related instruments
- As specified by a requirement, e.g., customer specification or instrument manufacturer recommendation

The calibration process for a temperature measurement system including a sensor and a transmitter is optimal when done as an operating system. While connected to the transmitter the sensor is exposed to a precision temperature source like a calibration block or a calibration bath held at a fixed temperature as measured by a standard sensor.

A standard sensor has accuracy traceability to a National Metrology Institute of the user country like NIST in the USA, NPL in the UK, and PTB in Germany among others. To communicate the quality of a calibration standard the calibration value is often accompanied by a traceable uncertainty statement to a stated confidence level.

Since it is often impractical to calibrate the transmitter and the sensor as a system, they are often calibrated individually and the sensor calibration data is then loaded into the transmitter. This procedure is quite adequate for the majority of applications. For the best accuracy sensor-transmitter matching should be performed and the system tested as a complete assembly.

TIP: The individual testing method does not account for any errors introduced from degradation / variation of leadwire and terminal corrosion which are a potential source of error for T/Cs and 3-wire RTD circuits. 4-wire RTD circuits are relatively immune from these issues.

5.7.3 Calibration Terms and Considerations

Calibration Tolerance: Every calibration should be performed to a specified tolerance which is defined as permissible deviation from a specified value that may be expressed in measurement units, percent of span, or percent of reading.

This term should not be confused with Accuracy which is defined as 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.

It is generally recommended that tolerance in measurement engineering units be used for calibration requirements. This will eliminate the potential errors in calculating % of span or % of reading values.

As an example from our transmitter range described above of 0 to 50 °C that has been specified with a tolerance of ± 0.25 °C the calculation would be:

$$(0.25\,^{\circ}C \div 50\,^{\circ}C) \times 16\ mA = 0.08\ mA$$

Generally, the tolerance would be listed as ± 0.25 °C *and* ± 0.08 mA on the calibration data sheet.

The determination of the tolerance should take into account the following:

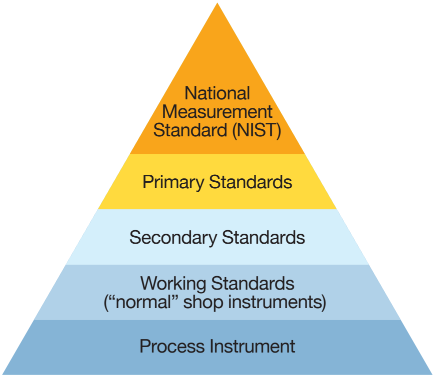
- Requirements of the process
- Capability of available test equipment
- Consistency with similar instruments at your facility
- Manufacturer's specified tolerance

TIP: Proper calibrator traceability should be an absolute requirement in any operating facility. Using calibration equipment that itself has not been properly calibrated will surely provide unreliable results that could lead to product quality issues, energy waste, non optimal production rates or possible dangerous conditions.

Accuracy Ratio: 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.

Using an accuracy ratio of 4:1 provides a safety margin that will make the calibration results less likely to be compromised by out-of-spec standards or test equipment or technician error.

Traceability: All calibrations should be performed traceable to a nationally or internationally recognized standard. As discussed above the standards used for calibration should be traceable to a National Metrology Institute like NIST in the USA. There may be many levels of traceability between your shop and NIST but the trail should exist and the tolerance of the standards fully understood. Your standards should be routinely calibrated by a "higher level authority" and the results properly documented. See 5.7.3a.



5.7.3a – Traceability Pyramid

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.

5.7.4 Proof Testing / Loop Testing

There are several terms applied to the process of verifying that an instrument loop is properly installed and functional in accordance with operational and functional specifications. A commonly used term is a loop test where a simulated signal is applied at the transmitter and the proper response is verified at the receiving device.

A more rigorous test is often referred to as proof testing – a term commonly used in Safety Instrumented Systems (SIS). In a proof test, the entire installation and functionality of the loop must be verified including sensors, transmitter, cabling, junction boxes, receivers, outputs, final control elements, and alarm/shutdown elements. Mechanical as well as electrical verification is performed.

Proof testing of safety related functions – referred to as safety Instrumented functions – is typically a very detailed procedure and must be completely and thoroughly documented.

5.7.5 Calibration Equipment

To calibrate a temperature sensor, it must be inserted into a known temperature and compared against a precision calibration standard sensor either by using a temperature dry block or liquid bath along with the appropriate display and control devices. For industrial applications the field dry block is typically favored due to its ruggedness, portability and safety. Liquid baths are more suited for laboratory use. The most important criterion in the calibration of temperature sensors is how accurate the sensors are at the same temperature.

Dry blocks are available with an internal reference PRT that will provide an accuracy capability that will be adequate for most sensors (Typically ± 0.5 °C). For sensors in more critical applications, an external reference sensor will provide greatly enhanced calibration accuracy capability. However, the calibration accuracy is limited by the stability and resolution of the dry block system. There are higher accuracy and resolution dry block models available that offer laboratory grade calibration capability. These are referred to as metrology grade dry blocks. See Figure 5.7.5a.

When selecting a field dry block you should consider:

- Temperature range
- Accuracy and stability
- Well flexibility (Bore sizes and available inserts)
- Portability
- Sensor immersion (Proper depth is important)
- Throughput (Number of sensors accommodated and automation features)

Dry blocks use inserts for the heated / cooled cavity that are bored out to various diameters to accommodate a wide variety of sensor diameters. These inserts may be easily interchanged as may be required.

Figure 5.7.5a – Typical Field Dry Block and Metrology Grade Dry Blocks (Courtesy of Beamex)

The uncertainty of calibration is not the same as the accuracy of the device. Many factors influence the total uncertainty, and performing calibration is not the least influencing factor. All heat sources show measurement errors due to their mechanical design and thermodynamic properties. These effects can be quantified to determine the heat source's contribution to the measurement uncertainty.

The major sources of measurement uncertainty are axial homogeneity (Along the length of the sensor), radial homogeneity (Horizontally between the sensors), loading effect (Multiple sensors in the block), stability (In the measurement zone), and immersion depth (typically 10x to15x sensor diameter). There are guidelines for minimizing measurement uncertainty that should be applied. In Europe they are from the European Association of National Metrology Institutes calibration guide for temperature blocks. (Euromet /cg-13/v.01).

Depending on the application, plant policies and procedures and accuracy requirements, sensors may be calibrated and the data recorded and subsequently loaded into the transmitter's database or to trim the transmitter. Or, alternatively, the sensor-transmitter assembly may be calibrated as a system.

TIP: It is important to note that calibrating the sensor and the transmitter separately does not take into account any error introduced by the interconnecting wiring. In the case of three-wire RTD and T/C installations this error can be significant. Four-wire RTD installations are not affected by wiring resistance imbalance or terminal corrosion.

5.7.5.1 Using a Temperature Calibration Block

A dry block consists of a heatable and/or coolable metallic block, controller, an internal control sensor and optional readout for an external reference sensor. There are fast and lightweight dry blocks for industrial field use as well as models that deliver near bath-level stability and resolution typical of laboratory use. See 5.7.5.1a.

The temperature range of the dry block must meet your minimum test requirements for the sensors being calibrated. The ideal calibration spans the entire usable range of the test sensor.

5.7.5.1a – Temperature Field Dry Block (Courtesy of Beamex)

After a full-range calibration of your temperature sensor, it's a good idea to check its accuracy in the precise range it is most often used. For example, if you calibrate an RTD over its full 0 – 100% range but intend to use it at the 65% point, it would be appropriate to verify its calibration at that specific point.

TIP: All calibrations should be performed traceable to a nationally or internationally recognized standard like NIST in the USA. There may be many levels of traceability between your shop and NIST but the trail should exist and the tolerance of the standards fully understood. Your standards should be routinely calibrated by a "higher level authority" and the results properly documented. Failure to follow this traceability will potentially lead to incorrect calibration of every temperature measurement system that is processed. Use of an inaccurate dry block system, decade box, millivolt or current source, and/or field calibrator could yield dozens or even hundreds of incorrectly calibrated instruments that could have a major impact on product quality, production throughput, energy usage and could even create dangerous operating conditions.

Accuracy and Stability are the two most critical specs on a dry block. Accuracy is how close the dry-well is to the programmed set-point. Stability is the temperature fluctuation of the instrument around the desired set-point over time. These two parameters add together to create the uncertainty of your calibration. If your dry-well does not meet your accuracy requirements and does not maintain a stable temperature, your probe could be reading a much different temperature than your display indicates.

A good rule of thumb is to make sure that your dry block is at least twice as accurate as the sensors you are checking. For critical applications three or four times better is suggested. A dry block calibration system should have accuracy traceability to a National Metrology Institute of the user country like NIST in the USA. See 5.7.3a page 41.

The dry block should have at least the set-point resolution of the accuracy it claims or your target accuracy. For example, if you are calibrating an RTD to ±0.5 °C at 100 °C and your instrument only displays temperature to ±1 °C, you obviously can't claim better than 1 °C (1.8 °F) for your calibration.

Depending on the number of sensors to be calibrated in a given time period there are two basic approaches:

- Use a single block with a capacity of one or more sensors and a reference standard. Typically three to five measurements are taken over the range of use of the sensor and the block must be stabilized at each of those temperatures before the measurement is taken. This is typically 15 to 30 minutes or more between readings. Some dry block systems are programmable to automatically cycle through the setpoint temperatures.

- Use multiple blocks with each one held at a specific calibration temperature and move the sensor being calibrated and the reference sensor sequentially to each block, allow them to stabilize, and then take the readings.

Assure that all connections to the measurement instruments are clean and tight.

5.7.5.2 Using a Universal Field Calibrator

Universal field calibrators are available in a variety of models from several major suppliers. Many models are HART compliant and others also interface with FOUNDATION™ fieldbus and Profibus PA.

They have the ability to simulate RTD, T/C, mv, voltage, and frequency signals that may be connected to a transmitter for calibration purposes. Many provide a dual screen capability to simultaneously see the simulated signal and the transmitter output. Some also have the ability to read signals from sensors and display the actual value of the variable.

Some instrument shops do not have field calibrators and must still rely on using decade boxes to simulate resistance values, and a current / voltage source to simulate volt, millivolt and current signals. As with all calibration instrumentation, these devices must have certified traceability for accuracy 4 times better than the calibrated device requires. Refer to 5.7.3

Tip: For calibrations carried out in areas of the plant classified as hazardous locations, it is necessary to use a calibrator that is properly certified for use in hazardous areas. These are typically intrinsically safe models (IS) and a typical international certification is certification to Ex ia IIC T4. This would be applicable to all vapor hazards where a temperature class of 135 °C in a 50 °C ambient is acceptable. In the USA FM certification is Intrinsically Safe for Class I/II/III, Division 1, Groups A, B, C,D, E, F, and G. Temperature Codes: T4A (T_{amb} = - 60 to 60 °C) and T5 (T_{amb} = – 60 to 50 °C)

5.7.5.3 Interfacing With Hart Instruments

Multifunction or HART-specific calibrators can operate as a HART Communicator to access all HART data in the instrument and trim or reconfigure as may be required. Additionally, they can be connected using an internal or external power supply to measure the analog output value and measure the HART digital value while applying a simulated test signal to the transmitter input. (RTD, T/C, mV, ohms, etc.)

To begin calibration the instrument's data must have been loaded into the calibrator either manually, from a calibration software entity or from an asset management system. An input signal may now be applied to the transmitter and the output values read. If so authorized, the transmitter may be trimmed or adjusted as may be required. Consult the user guide for your calibrator for specific procedures.

5.7.5.4 Interfacing with Foundation Fieldbus or Profibus PA Instruments

Interfacing to fieldbus enabled transmitters typically requires an interface module either within the calibrator or external from it. As with the HART devices, the instrument data must have been input to the calibrator either manually, from a calibration software entity or from an asset management system. The transmitter may be individually connected as a stand-alone device with the calibrator providing the power or with an external power supply and depending on the instrument's input signal, it is either generated/simulated or measured with the calibrator.

Alternatively, the calibrator may be connected to a live fieldbus segment for calibration, trimming and configuration verification or changes if required. Theoretically a segment may have up to 32 devices connected but few users connect more than 16 due to power supply considerations and other factors. Refer to the calibrator user manual for specific procedures for connecting, calibrating, trimming or configuration.

5.8 Calibration for High-Precision Application

There are applications in most industries where the utmost in accuracy is mandated for safety, product quality, production throughput, or custody transfer purposes.

For high precision applications the recommended practice is to perform sensor to transmitter matching. Although excellent results may be achieved by matching to sensors with 3-point or 5-point calibration curve data, the best possible accuracy is obtained when matching to a sensor using the sensor's Calendar van Dusen constants. Refer to Chapter 3 Temperature Measurement Basics section 3.1.4.3.3, Transmitter-Sensor Matching for more detail.

One of the most demanding high precision certifications is to have been certified to meet the European Union Measurement Instrument Directive (MID) for Custody Transfer metering of liquids and gases. This certification is allotted to a specific sensor model type used with a specific transmitter model and is available from only a very few manufacturers.

5.9 Introduction to Troubleshooting

Everything will eventually fail and finding the cause of the failure is a big part of troubleshooting. Understanding failure mechanisms is important when the cause of the failure is not readily apparent. Failures can take different forms including both hardware and software failures, functional due to misapplication or abuse or it could be systematic due to human error. Failures from a single cause can affect multiple instruments or loops and have complex cause and effect relationships.

Instrument failures can be classified in a number of different ways. They can fail safely, fail dangerously, or in a known state (Upscale drive or downscale drive for example) or in an "I don't care" state. The failures can be self-revealing or overt or it can be latent or covert.

The failed state in which you find an instrument is not always the actual failure. It may be in that state because it was "directed" to be in that state due to another failure unrelated to the instrument that stopped operating. An example would be an upscale or downscale drive of a transmitter with a sensor failure or shorted or open leadwire.

Others can be covert or hidden and may only be revealed when something is supposed to work on demand like a safety shutdown function and fails to respond to that demand.

Always review the applicable loop drawings for directed failure states before beginning to troubleshoot the problem. Close coordination with the operators to assure that safety is maintained and which loops may be taken out of service when is vitally important. Systematic troubleshooting is a skill taught in many training courses that can help resolve issues more quickly and cost effectively.

Troubleshooting frameworks or methodology can use any or all of three basic formats. It is typical to start with the easiest methods first and then proceed to the structured procedure only if necessary.

5.9.1 Symptom-Cause Tables

- Often found in vendor user manuals

5.9.2 Flowcharts or logical decision trees

- Consult vendor user manuals or troubleshooting training texts

5.9.3 Structured Approach to Troubleshooting

The following steps are typical of a structured approach to troubleshooting:

- Define the problem
- Get the facts - not just opinions
- Be sensitive to bias in the reporting - like blaming the instrument when it is an operational issue
- Collect information regarding the problem
- Symptoms, characteristics and parameters
  - What is working and what is not
  - Was anything changed since it was last operating properly
  - Any recent weather related issues (Lightning, heavy rain, snow)
  - Any recent cleaning or maintenance activity in the area (Welding?)
  - Inspect the instrument
  - Review all related documentation
- Analyze the information
- Categorize the information; eliminate the extraneous
- Is problem event or time driven
- Is there a history of repeat occurrence
- Similar-to analysis
  - How is this problem similar to another one; what is in common
- What is the exact problem?
- Where was it first noticed?
- When was it discovered?
- Consult user manuals
- Determine if enough information has been gathered
- Incrementally gather data and then review if there is enough to propose a solution

- Propose a solution or several solutions
- Which is most likely
- Which is quickest
- Which can be done without a shutdown
- What are the cost implications of each
- Test the proposed solution
- Secure the proper permissions and permits first if required
- Repair the problem
- Document completely (See Documentation section 4.2.6 below)
  - As found vs. as left
  - Failure analysis
  - Reports
  - Permit closeout
  - Update maintenance reports and databases
  - For transmitter replacement confirm all configuration details

5.10 Safety Instrumented System (SIS) Considerations

5.10.1 Background

A transmitter that is used in a SIS will be part of a Safety Instrumented Function (SIF).

A SIF is defined as a function to be implemented by a SIS which is intended to achieve or maintain a safe state for the process with respect to a specific hazardous event.

A SIF is a single set of actions and the corresponding equipment needed to identify a single hazard and act to bring the system to a safe state.

In the case of a temperature measurement the function could be to identify a dangerously high or low temperature condition by comparing the measurement against a predefined safe value and initiating an action to arrest or contain the situation should it exceed this limit. An example might be to initiate emergency cooling to a runaway reactor.

Depending on the consequences of this event happening, the safety engineers will have selected a Safety Integrity Level (SIL) for this SIF which defines a target for the probability of failure of this measurement. A SIL 2 must be more reliable than a SIL 1 and a SIL 3 must be more reliable than a SIL 2 function and will be designed accordingly.

5.10.2 The Technician's Role and Responsibilities

For any safety related device there will be a very detailed and precise test plan for the unit operation. The safety standard requires that all personnel involved with SIS should have the proper qualifications and training.

Note that transmitter output is not safety-rated during: configuration changes, multi-drop, and loop test. Alternative means should be used to ensure process safety during transmitter configuration, maintenance and testing activities.

To ensure compliance with the IEC 61511 safety standard, there are normally permissions and permits that must be completed to take a loop out of service and the testing procedure must be followed to the letter and often witnessed and signed and co-signed. Any abnormalities or failures must be carefully documented with multiple sign-off signatures. Any changes made to the loop must be incorporated into the Management of Change (MOC) documentation. These include any device replacement or upgrade and any configuration and calibration changes.

The test procedure will typically have steps to ensure that there is proper communication from the field transmitter to the DCS and that a proper signal is being received and that all alarm values are properly configured and operational.

The procedure will also include verification that the final control element properly functions in accordance with the Safety Requirements Specification (SRS).

Since the SIF also includes the sensor, its lead-wires, the signal wiring and any terminations, these also must all be tested and verified. The ultimate and ideal test is to subject the sensor in situ to a precisely known standard temperature such as a calibration block or bath which forces a simultaneous test of all components of the SIF. Since this is rarely practical in the real world, other simulation sources are typically used and the sensor and its circuitry independently tested and calibrated.

5.11 Diagnostics

While all smart transmitters have diagnostics, some are considerably more extensive than others. Those with a HART™, FOUNDATION™ fieldbus, or Profibus protocol offer the most sophistication. Each protocol uses different technologies and different ways of accessing the diagnostic information described below.

The Control System Technician (CST) should coordinate with operations to routinely review available diagnostic information reported via the DCS, PLC, field communicator, and/or asset management system.

Discussed below are common diagnostic capabilities and maintenance flags available on temperature transmitters. Consult the product data sheets and the user manuals for availability on your particular product.

5.11.1 Basic Transmitter Diagnostics

Typical information that is useful for diagnostic and maintenance purposes includes:

- Sensor(s) failures – open, shorted, intermittent
  - The transmitter has detected an open or shorted sensor condition. The sensor(s) might be disconnected, connected improperly, or malfunctioning. Check the sensor connections and sensor continuity.
- Field Device Malfunction
  - The device has detected a hardware error or failure on the device. This pertains to a variety of errors that can occur. Malfunctions in the memory, A/D converters, CPU, etc are covered under this status bit.
- Process Variable (PV) Out of Limits
  - The HART transmitter is reporting that the primary variable read by the transmitter is outside of the 4-20 mA range. This signal can be used to detect open/short circuits in the transmitter wiring.
- Process Variable (PV) Output Saturated
  - The analog and digital signals for the Primary Variable are beyond their limits and no longer represent the true applied process. If the process variable goes outside of the 4-20 mA range, the HART transmitter will drive the mA output and the PV to the saturation values, but no further. The transmitter will clamp the analog output and PV to the saturation values (not the 4 and 20 mA values). PV's between the 4-20 mA limits and the saturation limits may still be valid signals.
- Process Variable (PV) Output Fixed
  - The analog and digital signals for the Primary Variable are held at the requested value. They will not respond to the applied process. The output is fixed when a transmitter has been taken out of service during calibration or maintenance (changing a range, for example). Unless the transmitter has been put back in service, the outputs will continue to be fixed indefinitely.

WHAT BENEFITS CAN BE GAINED BY USING TRANSMITTER DIAGNOSTICS?

While all smart transmitters have diagnostics, some are considerably more extensive than others. Those with a HART™, FOUNDATION™ fieldbus, or Profibus protocol offer the most sophistication.

There are internal diagnostics that monitor transmitter functionality and output validity. Also, there are a wide range of external diagnostics that monitor the measurement signal for such things as drift, degradation, measurement validity, and broken or damaged leads among others.

Transmitters initiate either Alerts or Alarms based on these diagnostic processes.

Alerts cover diagnostics that are determined not to affect the transmitter's ability to output the correct measurement signal and therefore will not interrupt the 4-20 mA output. An example is "Process Variable Out-of-Range".

Alarms cover diagnostics that are determined to affect the transmitter's ability to output a correct value of the measurement. Detected alarms will drive the transmitter output either high or low depending on user's choice.

Alerts and alarms can be read on a local indicator (if so specified), on a field communicator or on a HART-compliant monitoring system like Emerson Process Management's AMS Suite application.

Refer to:

5.11.1 – Basic Transmitter Diagnostics

3.1.8 – Diagnostics

- Analog-Digital Mismatch
  - The HART transmitter is reporting a difference between the analog 4-20 mA signal and the digital Primary Variable (PV) signal. This functionality can be used to determine a small ground in the home run cable to the instrument or an intermittent device. If a small ground exists in the loop, any alarm trip limit of the loop may never be reached even under trip conditions due to earth leakage.
- Loss of Digital Comms
  - This status bit is set when the HART digital communications with the device is lost. The 4-20 mA analog signal may still be valid, but the digital HART signal is not available.
- Hot back-up initiated (for dual sensors)
  - Upon failure of the primary sensor, the transmitter will instantly change over to the secondary sensor. The primary and secondary may be either RTDs or T/Cs or one of each to reduce common cause failure issues.
- Sensor drift alert (with dual sensors)
  - Sensor Drift Alert notifies the control system of the degradation of a sensor that is causing its measurement signal to drift away from the actual value, thus decreasing the measurement integrity. By using two sensor inputs, the difference between the two sensors is monitored. When the difference becomes greater than a value entered by the user, the transmitter sends an alert to indicate a sensor drift condition.
  - This feature may be used in conjunction with a hot back-up feature to instantly switch the transmitter from the drifting sensor to the secondary sensor.
  - The two sensors can be RTDs, T/Cs or one of each for reduction of common cause factors
- Thermocouple Degradation Diagnostic
  - This feature acts as a gauge of general thermocouple health and is indicative of any major changes in the status of the thermocouple or the thermocouple loop. The transmitter monitors the resistance of the thermocouple loop to detect drift conditions or wiring condition changes. The transmitter uses a baseline and threshold Trigger value and reports the suspected status of the thermocouple. This feature is not intended to be a precise measurement of thermocouple status, but is a general
- Measurement Validation
  - Deviation Alarming
    - Before a sensor fails, it will exhibit signs of degradation such as increased signal noise which will often result in inaccurate on-scale readings. Measurement Validation is a diagnostic that can provide validation of temperature measurement data, ensuring visibility of measurement and process abnormalities before a sensor failure occurs. Measurement Validation monitors the signal noise and uses it to calculate a deviation value indicating the magnitude of the noise which is compared to a user selected alert limit. When this limit is exceeded, the user is notified, allowing action to be taken. Measurement Validation can also detect on-scale failures associated with loose or corroded connections, high vibration and electronic interference which can contribute to a signal noise increase.
  - Rate-of Change Alarming
    - In addition to detecting on-scale failures and validating measurement values, Measurement Validation also performs a rate of change calculation which can be used to identify abnormally fast temperature changes that could indicate a runaway reaction condition even before alarm conditions are met.
- Minimum and Maximum Temperature Tracking
  - Minimum and Maximum Tracking can record lifetime minimum and maximum temperatures with date and time stamps. This feature records values for Sensor 1, Sensor 2, differential and terminal (body) temperatures.
- Statistical Process Monitoring Algorithm
  - This feature provides basic information regarding the behavior of process measurements such as PID control block and actual valve position. The algorithm can monitor up to four user selected variables. All variables must reside in a scheduled function block contained in the device. This algorithm can perform higher levels of diagnostics by distribution of computational power to field devices. The two statistical parameters monitored by the Statistical Process Monitoring are mean and standard deviation. By using the mean and standard deviation, the process or control levels and dynamics can be monitored for change over time. The algorithm also provides:

- Configurable limits/alarms for High variation, low dynamics, and mean changes with respect to the learned levels
- Necessary statistical information for Regulatory Control Loop Diagnostics, Root Cause Diagnostics, and Operations Diagnostics.

- Transmitter Diagnostics Logging

– This feature will store advanced diagnostics information between device resets. This feature stores what caused the transmitter to go into alarm even if that event has disappeared. For example, if the transmitter detects an open sensor due to a loose terminal connection the transmitter will go into alarm. If, due to vibration, that wire begins making a good connection, the transmitter will come out of alarm. This jumping in and out of alarm is very frustrating when determining what is causing the problem. However, the Diagnostics Logging feature will keep track of what caused the transmitter to go into alarm and will save valuable debugging time.

5.12 Documentation

Every plant will have documentation policies and procedures that must be followed. There are requirements before, during and after any procedure.

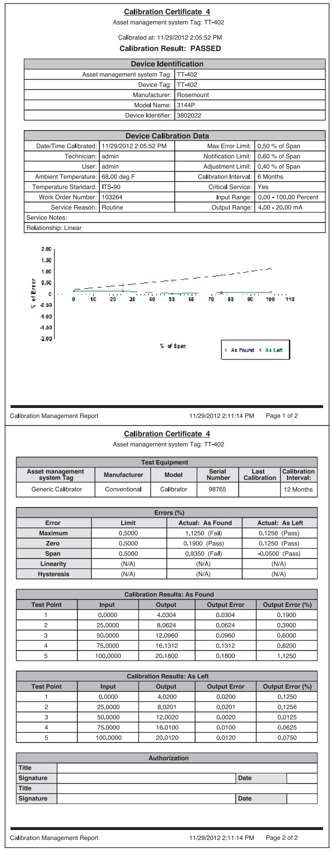
> *TIP: If a documenting calibrator is being used in conjunction with a calibration management software entity or an asset management system, much of the following information will be automatically provided in the form of reports, graphs and logs.*

5.12.1 The Planning Stage

- Review trouble reports and operational requests for troubleshooting
- Review diagnostics logs looking for abnormalities
- Determine what requests for permits must be completed for any required procedures
- Secure required loop drawings, P&IDs, specification data sheets, vendor manuals, test procedure checklists, etc.

5.12.2 The Implementation Phase

- As-found reports
- Procedure checklists



Calibration Certificate 4

Asset management system Tag: TT-402

Calibrated at: 11/29/2012 2:05:52 PM

Calibration Result: PASSED

Device Identification	
Asset management system Tag:	TT-402
Device Tag:	TT-402
Manufacturer:	Rosemount
Model Name:	3144P
Device Identifier:	3802022

Device Calibration Data			
Date/Time Calibrated:	11/29/2012 2:05:52 PM	Max Error Limit:	0.50 % of Span
Technician:	admin	Notification Limit:	0.60 % of Span
User:	admin	Adjustment Limit:	0.40 % of Span
Ambient Temperature:	68.00 deg F	Calibration Interval:	6 Months
Temperature Standard:	ITS-90	Critical Service:	Yes
Work Order Number:	103264	Input Range:	0.00 - 100.00 Percent
Service Reason:	Routine	Output Range:	4.00 - 20.00 mA
Service Notes:			
Relationship: Linear			

Calibration Management Report 11/29/2012 2:11:14 PM Page 1 of 2

Calibration Certificate 4

Asset management system Tag: TT-402

Test Equipment					
Asset management system Tag	Manufacturer	Model	Serial Number	Last Calibration	Calibration Interval:
Generic Calibrator	Conventional	Calibrator	98765		12 Months

Errors (%)			
Error	Limit	Actual: As Found	Actual: As Left
Maximum	0.5000	1.1250 (Fail)	0.1256 (Pass)
Zero	0.5000	0.1900 (Pass)	0.1250 (Pass)
Span	0.5000	0.9350 (Fail)	-0.0500 (Pass)
Linearity	(N/A)	(N/A)	(N/A)
Hysteresis	(N/A)	(N/A)	(N/A)

Calibration Results: As Found				
Test Point	Input	Output	Output Error	Output Error (%)
1	0.0000	4.0304	0.0304	0.1900
2	25.0000	8.0624	0.0624	0.3900
3	50.0000	12.0960	0.0960	0.6000
4	75.0000	16.1312	0.1312	0.8200
5	100.0000	20.1800	0.1800	1.1250

Calibration Results: As Left				
Test Point	Input	Output	Output Error	Output Error (%)
1	0.0000	4.0200	0.0200	0.1250
2	25.0000	8.0201	0.0201	0.1256
3	50.0000	12.0020	0.0020	0.0125
4	75.0000	16.0100	0.0100	0.0625
5	100.0000	20.0120	0.0120	0.0750

Authorization			
Title			
Signature		Date	
Title			
Signature		Date	

Calibration Management Report 11/29/2012 2:11:14 PM Page 2 of 2

Figure 5.12a – Typical Calibration Documentation

5.12.3 Completion Phase

- Complete calibration data sheet with as-left data (See Figure 5.12a)
- Close out work permits including finalizing any LOTO locations
- Update loop sheets
- Update tagging
- Complete MOC report if required
- Update any associated operational procedures
- Update P&ID if required
- Update specification sheet if required
- Update appropriate computer databases
- File hard copies of completed reports as backups

6 Best Practices

Best Practices

A Compendium of Challenging Applications Each With an Analysis and Recommended Solution(s)

It is the intent of this chapter to provide a variety of common user application challenges and to present one or more options that provide a viable and cost effective solution.

The intent is to promote your intuitive analysis of your specific problem as a path to your selection of a proper solution

As compared to the vast array of application experience at Emerson Process Management this section merely scratches the surface.

Best Practices #1

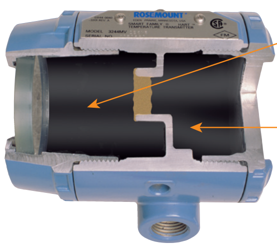
Category:
How to Get the Most Accurate and Reliable Temperature Measurement System

The Challenge:
The application requires a precision temperature measurement at a specific level in a distillation column. The following requirements and conditions have been documented:

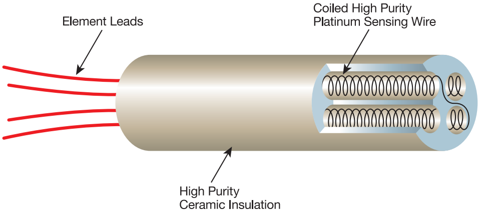
- Temperature range is 0 to 80 °C (32 - 176 °F)
- Control point is 60 °C ± 0.1 °C (140 °F)
- Column throughput variation due to off-spec temperature affects other levels of the column with cascading detrimental effects to product quality, energy usage and throughput indicating that this measurement must have the best possible performance and complete on-board diagnostic capability
- To maximize performance and minimize installation costs it is preferable to mount the transmitter integrally with the sensor-thermowell assembly

Analysis and Solution:

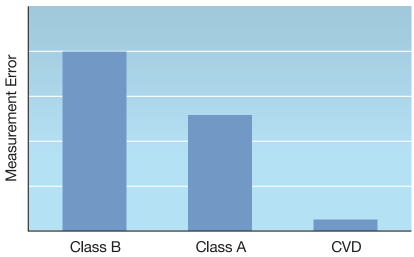
- Due to the significant consequences to the process that a failure of this measurement would cause, the sensor/transmitter system must be designed to have the best possible reliability.
- Select a top-of-the-line temperature transmitter from a major supplier to ensure the system performance will meet the process requirements
  – Opt for a model that uses a dual-compartment housing to ensure the greatest tolerance for adverse environmental conditions



- Figure 3.1.10.2a – Dual Compartment Housing
- The application requires using a precision platinum RTD-based system since it is impossible for a T/C based system to achieve the accuracy and stability requirements of this measurement
- The system must be designed in a four-wire configuration.
  – A three-wire system will always have measurement error due to lead wire imbalance. Note that this fact precludes using a dual element sensor since a dual sensor only provides three wires per sensor.
- Select a 0.25” diameter spring-loaded, tip sensitive, helical wire-wound style of platinum RTD sensor to provide the best possible sensor accuracy and reliability

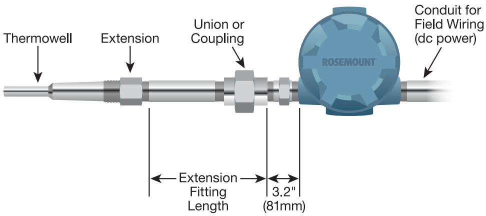


- The best possible performance is achieved when the sensor is matched to the transmitter using the sensor’s specific Callendar Van Dusen (CVD) constants.
  – System accuracy will be about 5 times better than standard calibration providing a comfortable margin vs. the control requirement of the process



System Calibration Comparing a System Using a Class A Sensor vs. a System Using a Class B Sensor vs. a CVD Matched Sensor

- Order the system assembled, tested and calibrated complete with a thermowell as a unit assembly from the factory
  – Single source responsibility for the complete calibrated system package from the factory ensures best performance
  – Should a sensor fail, ensure that the replacement sensor is provided with CVD constants and the system is recalibrated using those constants



Sensor – Transmitter Preassembled System

Best Practices # 2

Category:
Directly Wire Sensors to Control System or Use a Transmitter

The Challenge:
When designing a control system for a plant facility, engineers often must make decisions about the use of directly connecting sensors to the control system or the use of transmitters. The engineers must consider a myriad of performance and cost of ownership issues to make a proper decision.

Analysis and Solution:
Here are some factors that should be considered. To be useful for control, monitoring or logging of the measured temperature, the signal must be communicated from the field measurement point to the control room. Many plant sites have established preferences on how this is accomplished; most commonly using field mounted transmitters or direct wiring from the field to control room device input cards. Each method has its proponents but cost of ownership and performance considerations make the case for a strong preference for using transmitters over using direct wiring. In some plants remote I/O modules from the control system present a viable alternative.

Direct wiring, as the name implies, is characterized by connecting field sensors directly to input card racks within control room systems where it is then conditioned or converted into an analog signal representing the temperature measurement for use in that system. These control room systems could be a Distributed Control System (DCS), a Programmable Logic Controller (PLC), a data logger, or a controller. The sensor signals can be directly connected to the control system I/O subsystems, connected to remote I/O, or use multiplexers.

For RTD sensors, standard copper extension wire is used for all four leads. However, for thermocouple sensors, specially matched extension wire must be used or huge measurement errors will result. For more detail refer to the "Connecting to the Control System" section 4.3.4.

The transmitter converts the measurement input signal from RTDs and T/C sensors to a high level robust 4-20 mA output signal that is highly immune from Electromagnetic Interference (EMI), and Radio Frequency Interference (RFI) and most models support the HART protocol. Other fieldbus models have a digital signal output for connection to remote devices or systems.

There are many advantages of using transmitters vs. direct wiring. Some of the most salient are listed below and for a more complete list refer to the "Connecting to the Control System" section 4.3.4.

Cost of ownership of using a transmitter approach vs. direct wiring awards a clear advantage to the transmitter for the majority of applications. Considerations include:

- Higher performance is assured since a transmitter-sensor assembly may be calibrated as a system for optimal accuracy which cannot be done with a direct wired system and sensor – transmitter matching may also be performed
- Transmitter accuracy and performance is always better than what can be expected from direct wired system design by a factor of about 2:1
- There are many "intelligent" features and options available in transmitters that are not available or require special software programming in most DCSs including hot back-up, sensor drift alerts, thermocouple degradation, min-max tracking, and intermittent sensor detection among others.
- The robust transmitter output signal is far less susceptible to EMI and RFI interference than low level sensor signals where the extension cables act as antennas for the noise signals
- Transmitters can be configured to fail to predetermine output levels.
- Trouble shooting and maintenance time is reduced by utilizing transmitter diagnostics that are not available or are quite limited in input cards
- Sensor types can be changed from T/C to RTD or to a different type of T/C or RTD and the same transmitter is easily reconfigured to the new

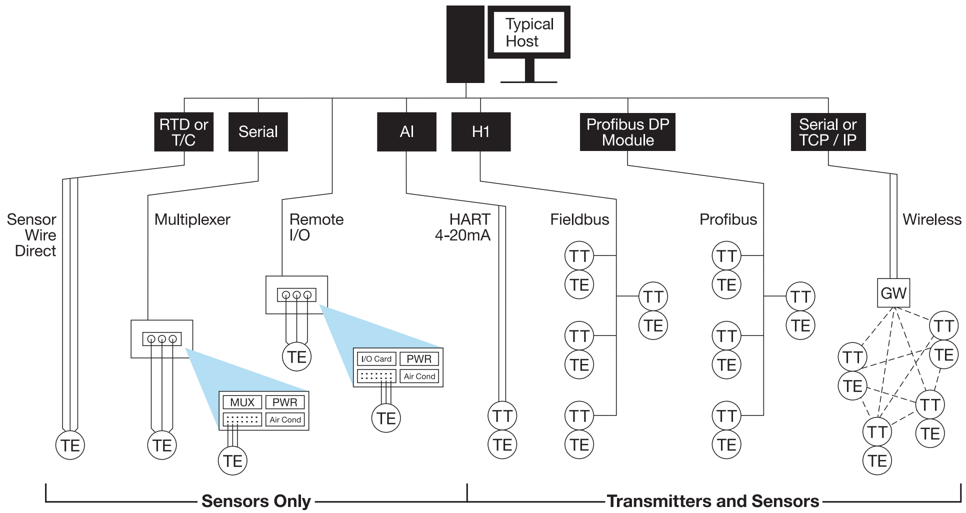


Figure 4.3.1a

sensor type. The output cable and the DCS input card stay the same. For direct wiring extension cable would likely need to be changed as well as the input card in the DCS.

- There is only one type of extension wire and it can be purchased in larger lots to reduce cost. Twisted pair shielded copper signal wire is far less expensive than multiple types of T/C extension wire or 4-wire RTD extension cable. Note that 4-wire RTDs are highly recommended vs. 3-wire systems
- Only one type of high level input card is required for the control system instead of a mixture of high level and low level cards. Low level sensor input cards are typically more expensive than 4-20 mA input cards and spares inventory is reduced
- Single vendor sourcing saves multiple specification sheets, quotation requests, bid reviews and purchase orders
- Drafting costs are lower with only a transmitter symbol to show for a field device and only copper wire to show on the P&ID and bill of material
- The requirement for using different types of T/C extension wire often leads to wiring errors at installation. This problem is eliminated by having all copper for the field wiring
- All transmitters can be the same manufacturer and model minimizing spares
- No need to periodically replace degraded T/C extension wire. Copper wire can last for decades
- Transmitters offer a local indication option which improves operator interface and reduces maintenance time
- For T/C applications, accuracy deterioration due to extension wire degradation can be severe

A system diagram illustrating all technologies is in Figure 4.3.1a.

Pros and Cons of these technologies are compared in Figure 4.3.1b.

Technology	Pros and Cons
Wire Sensors Directly to DCS	• High Wiring and Infrastructure Cost • Prone to Interference • High Maintenance • Limited Feature Functionality and Performance vs. Transmitter
Multiplexors	• Dated Technology • Slow Updates • Reliability Issues • Limited Accuracy and Performance Specifications • Area Certification and Environmental Limitations • Limited Parts, Service
Control System Remote I/O Racks	• Good Basic Capability • Proprietary Infrastructure • Limited Feature Functionality and Performance vs. Transmitter • Area Certification and Environmental Limitations
Transmitters and Sensors	• Highest Accuracy • Excellent Noise Immunity • Lowest Cost of Ownership • Wide Choice of Measurement Enhancement Features

Figure 4.3.1b – System I/O Option Comparison

Best Practices #3

Category:
High Ambient Temperature Mounting of Temperature Transmitter

The Challenge:
The application requires a temperature measurement on a high temperature reactor. The following conditions have been documented:

- The ambient temperature at the surface of the reactor at the measuring point ranges from 75 to 100 °C. (167 - 212 °F) The thick layer of insulation helps somewhat to mitigate the radiated heat but concern exists about mounting electronics onto the reactor.
- Local indication is required for the area operator to verify the measured temperature and to ensure that the transmitter is operating properly.
- HART communication capability is required such that the operational and configuration integrity of the transmitter may be remotely accessed, verified and changed as may be required.

Analysis and Solution:

- Due to the high ambient temperature at the measuring point, a remote mounted transmitter is the proper solution
  - Select a nearby location with ambient conditions cool enough so as to be reasonably comfortable for the area operator
  - Ensure that it is protected from damage, splashing and dripping sources

Figure 3.1.3.5b – Remote Mounted Field Transmitter

- Select a HART-smart temperature transmitter with a dual-compartment housing to ensure the greatest tolerance for adverse environmental conditions
  - The transmitter should be specified with an integral LCD indicator to locally display process temperature, output signal and diagnostic information
  - It should have the ability to monitor dual sensor inputs as a consideration for the adverse conditions

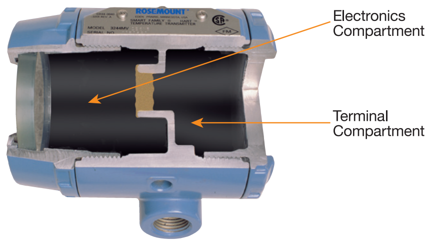


Figure 3.1.10.2a – Dual Compartment Housing

- For temperature ranges below 600 °C (1112 °F), select an RTD sensor.
  - Higher temperatures may require use of a T/C
  - Dual sensors should be considered
- Single sensor with dual elements
- Two separate sensors offer highest reliability
  - Refer to the Temperature Measurement Basics Chapter 3.2 for more detailed suggestions
- Connect the transmitter to the sensor assembly using properly specified twisted and shielded 4-wire copper conductor cable run in a suitable conduit or use a suitable armored cable.
  - The shield should be connected to the transmitter output cable shield and isolated from the transmitter enclosure.
  - Note that some plant standards require that the sensor shield be grounded to the transmitter housing and, in this case, the output cable shield is left floating at the measurement point and grounded at the receiver. Refer to Engineering and Design Chapter section 4.3.6.
- The HART signal that is superimposed on the analog output signal of transmitters has a wealth of data that can provide useful information. This

typically includes the temperature inside the transmitter housing and the process temperature. Some transmitters have an on-board feature that keeps records of both the process and ambient temperature values. Alternatively the HART data may be accessed using a field communicator or by an asset management system. This enables a user to verify that housing temperatures have not exceeded recommended limits. Operating a transmitter above its published maximum operating temperature may cause premature failure and/or invalid outputs. Operating it below its rated ambient temperature may lead to degradation of the accuracy.

- The HART data also includes sensor diagnostics information for open or shorted leads that often is accessed by the internal transmitter diagnostics and displayed on the LCD or alternatively or supplementally they can also be accessed by a field communicator or an asset management system. In an asset management system any abnormal conditions can be configured to trigger an alert or alarm in the Distributed Control System (DCS).

Best Practices # 4

Category:
High Vibration at Measurement Location

The Challenge:
The pipeline where the measurement is to be made is under varying but constant vibration. We want to use an RTD but are unsure of how to select the right type and how to install it.

Analysis and Solution:
In general a thin film style of RTD is a better choice. It has a much lower mass than a mandrel style wire-wound RTD and therefore is more likely to withstand the vibration of this pipeline by approximately a factor of two to one. The RTD should be a spring-loaded design to fit tightly against the bottom of the thermowell bore.

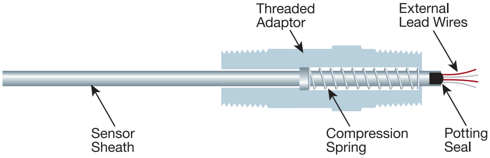


Figure 3.2.3.1.2b – Spring Loaded Sensor

A typical vibration spec for a sensor is:

Vibration Limits: ±0.05% maximum ice-point resistance shift due to 30 minutes of 14 g peak vibration from 5 to 350 Hz at 20 °C (68 °F) for unsupported stem length of less than 6 inches.

There are also some designs of helical coil style of wire-wound RTDs that are resistant to vibration damage and may be a consideration.

Although it would seem that redundancy provided by using a dual element RTD would extend the life, in reality dual elements in the same sheath provide little benefit since both elements are subjected to the same common cause of potential damage and are likely to suffer the same fate. However, for critical processes where an unexpected failure is unacceptable, the dual element sensor connected to a transmitter with the Hot Backup® feature could provide enough time to make an orderly sensor replacement.

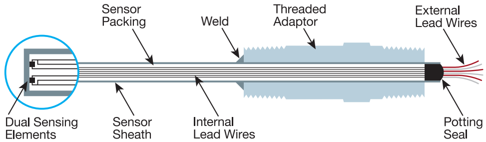


Figure 3.2.3.1.1a – Dual Element Sensor

If the consequences of measurement failure justify the expense, an entire redundant sensor-transmitter assembly may be justified. A heavy duty T/C sensor could be used to provide a potentially more robust measurement but at the sacrifice of accuracy since a T/C measurement is most often less accurate than an RTD measurement. The DCS or a stand-alone selector module can transfer to the secondary measurement should the primary measurement fail.

The ultimate solution – often used in Safety Instrumented Systems (SIS) - is a voting scheme of 2 out of 3 transmitters (2oo3). And again they could use different sensor technologies and possibly even different model series transmitters for diversity.

A remote mount transmitter removes the transmitter from the vibration at the measurement site and is strongly encouraged. Mount the transmitter as close as is reasonable to the sensors to minimize sensor lead length that is exposed to electrical interference and potential error.

Figure 3.1.3.5b – Remote Mounted Transmitter

The thermowell is an important consideration for such applications and proper diligence should be used in its selection. In general, a flanged or welded style will withstand adverse conditions better than a threaded style. There are analysis tools used by manufacturers that are available to the user to predict the best choice of thermowell for not only the pipe vibration but also the vibration induced both transverse and parallel to the well by vortex shedding. The tool automates the Wave Frequency Calculation process to ensure the proper well design and material is selected. Detailed guidance and procedures are spelled out in ASME PTC 19.3 TW 2010 which is described in detail in Chapter 3.3. Refer to Thermowell Calculation white paper in section 9.1

Figure 3.3.3.3.3a – Tapered Flanged Thermowell

Best Practices # 5

Category:
Understanding Measurement Error

The Challenge:
There are some processes where an accurate and stable measurement is crucial to product quality, production throughput, or cost control. An example is a batch production in pharmaceutical manufacturing where a very expensive batch can be ruined by a very small temperature offset error. Another is temperature compensation of a custody transfer flow measurement where a very small error can mean many thousands of dollars in potential lost revenue.

Having an understanding of how component selection affects the performance of the temperature measurement system is very important in achieving the measurement accuracy and stability goal of the application.

Analysis and Solution:
A temperature measurement system includes the sensor, the transmitter and the thermowell. Error analysis will have factors associated with both the transmitter and the sensor. Transmitter specifications are often confusing to read and can be deceptive if not read carefully and fully understood. To evaluate different transmitters, both the specifications and their impact on performance must be understood.

Selecting a transmitter will certainly include preferences for features and options but it must also give due consideration to its accuracy and performance specifications with respect to the particular requirements of the application. For example, ambient temperature effects will be a bigger factor for transmitters in an outdoor environment vs. those mounted in a controlled indoor environment. The calibrated span will also be a factor as will vibration effects. Different manufacturers often state accuracy and performance specifications in different ways. Some specify accuracy as percent of calibrated span, others as percent of Upper Range Limit (URL) and others as percent of reading. The error calculations for each case will have different results.

A method to do a consistent performance comparison between various transmitters is to do a total probable error (TPE) analysis based on the published performance specifications of each transmitter and sensor. This will provide an accurate indication of expected performance under the specific conditions and changes in conditions of your application. The components of this calculation include the root sum square of the multiple transmitter and sensor accuracy effects.

System Accuracy

$$= \sqrt{(\text{Transmitter Accuracy})^2 + (\text{Sensor Accuracy})^2}$$

$$= \sqrt{\text{Digital}^2 + \text{D/A}^2 + \text{DigitalTempEffects}^2 + \text{D/AEffecys}^2 + \text{Sensor Accuracy}^2}$$

Although both reliability and performance of a transmitter are design dependent, they are not interchangeable and should be considered separately. The same can be said about sensors. In some applications the reliability of the transmitter to continue to perform may be more desirable than the actual level of performance. In addition to the degree of performance indicated by the TPE, the final choice of a transmitter should also include factors of reliability, the appropriateness of the transmitter to the application, the features included and the overall cost of ownership. Refer to Section 4.2.7 for TPE calculation examples. Note that most reputable manufacturers will provide these calculations for documentation and traceability if specified and requested.

Best Practice # 6

Category:
Mount Transmitter in a Tight Space in Field-Mounted Junction Box

The Challenge:
We need to add many new temperature transmitters to a field-mounted junction box in a field location in the proximity of the measurement site. However, we have severe space limitations. We need a compact high density style of transmitter that will fit into the small available space.

Analysis and Solution:
There are several solutions for this application that are presented in order of preference.

The first solution is to use high density multichannel transmitters. These transmitters accept up to 8 sensor inputs and are useful in applications where many temperature measurement points are concentrated in one area. High density transmitters minimize installation costs in applications such as heat exchangers, boilers, chemical reactors, and distillation columns. They are also often used for temperature profiling of furnaces and reactors.

Figure 3.1.2.3b – Multichannel Transmitters

The second solution for mounting in this limited space is a DIN rail mounted style of transmitter where many transmitters can easily fit into the available space and still have room for the cabling wire-way as well.

Figure 3.1.10.3a – Rail-mount Transmitters

A third solution is a DIN A or DIN B head mount or “hockey puck” style that can be DIN rail mounted into the cabinet using clips.

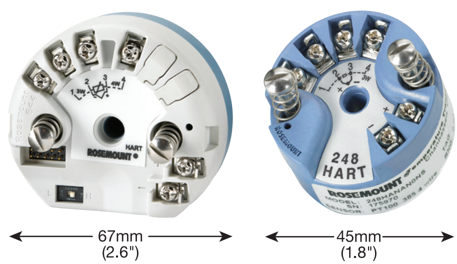


Figure 3.1.10.1a – DIN A and DIN B Head-mount Housing Styles

The transmitters are connected to the nearby sensors to complete the system.

Since this is a field-mounted junction box with existing devices mounted within, it is assumed that the general purpose or IS certifications of a rail mount configuration meet the area requirements. For explosion proof applications a head mounted style in an approved enclosure would be required and they would not fit into the existing enclosure.

A fourth solution is to connect all sensors directly to a DCS / BPCS. While this solution does not require any field cabinet space, it does carry the added cost of long runs of extension cables and the added exposure of the low level sensor signals to electrical interference from EMI and RFI.

Best Practices #7

Category:
Sensor Redundancy

The Challenge:
A critical temperature measurement on a reactor must have the highest possible availability for product quality considerations. A failure of this measurement would result in loss of control and expensive lost production penalties. Plant management wants to make this measurement using some sort of redundancy to optimize measurement availability.

Analysis and Solution:
Three commonly used solutions to this challenge are presented ranging from the least expensive to purchase and install and with the lowest relative availability up through the most expensive with the highest availability. However, the cost of ownership analysis may indicate that the cost of lost production due to a measurement failure "event" is so high that the best possible solution could have the lowest long term cost of ownership and therefore the best cost to benefit ratio.

A basic solution is to specify a transmitter with a sensor redundancy option. With this option two sensing elements are connected to the transmitter. The output of the transmitter will be the signal from the primary sensor. However, should the primary sensor fail, the redundancy option will instantly switch to the secondary sensor to provide the output thus eliminating any interruption of control of the loop. An alert is typically generated to notify the operator that one of the sensors has failed so that it can be replaced on a scheduled basis. This is commonly known as the Hot Backup® feature.

A high quality dual element RTD should be selected that has redundant elements within the same sheath that are connected to the transmitter with one element serving as the primary sensor and the other as the secondary or backup sensor. With this approach, there exists the likelihood that whatever might cause the primary sensor to fail would also cause the secondary to fail. These are referred to as common cause failures and could stem from such things as vibration, a manufacturing impurity, or physical damage. The transmitter is also a single point of failure.

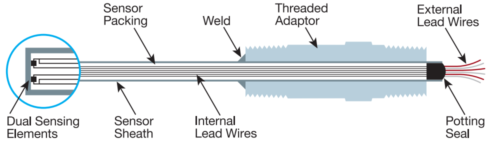


Figure 3.2.3.1.1a - Dual Element RTD Sensor

Depending on plant preference and mounting location, the transmitter may be mounted integrally with the sensor or remotely nearby.

Another alternative solution is to use two separate RTDs each in their own sheath and thermowell and both connected to the transmitter. This effectively reduces the potential common cause failure probability of the sensor dramatically but does not address the single point of failure of the transmitter.

Yet another solution is to use one RTD and one T/C sensor for redundancy to possibly provide protection against common cause failures.

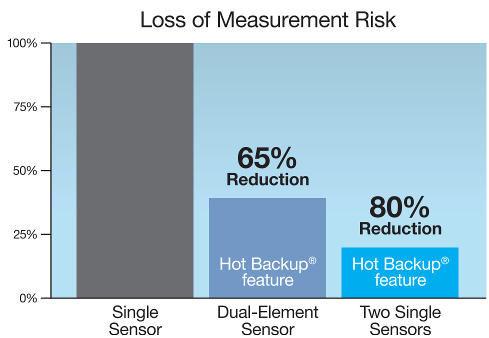


Figure 3.1.6.6a - The Hot Backup® feature Prevents Primary Sensor Failure from Disrupting Process Control

A higher reliability solution is to install two entirely independent sensor-transmitter systems connected individually to the control system and voted to assure that a failed measurement is rejected in favor of a good measurement.

An even higher availability solution is to use three independent sensor-transmitter systems and use a median select function in the control system.

Best Practices #8

Category:
Wake Frequency Calculations and Thermowell Selection

The Challenge:
Thermowell failures are often associated with one or more of the following: high drag forces, excessive static pressure, high temperature, corrosion, erosion, material selection, improper installation technique, and by fluid induced vibration.

Most failures are caused by fluid induced vibration. When fluid flows past a thermowell inserted into a pipe or duct, vortices form at both sides of the well and detach first from one side and then from the other in an alternating pattern. This phenomenon known as vortex shedding creates alternating forces on the well resulting in alternating transverse deflection at a frequency often referred to as the wake frequency. There are other forces produced along the axial or parallel axis of the flow. When choosing a thermowell for an application some method must be used to ensure that these alternating forces do not approach the natural frequency of the well causing harmonic vibration and probable failure.

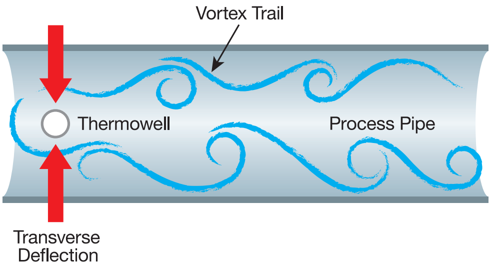


Figure 3.3.7.1b – The von Karman Trail – Showing Transverse Force Deflection and Direction

Analysis and Solution:
The system designer has the dilemma of trying to maximize system accuracy and response by using a thinner design thermowell long enough to get into the turbulent flow area and also ensuring that the well is thick enough and short enough to avoid wake frequency induced vibration.

Figure 3.3.7.1a - Example of a Thermowell Failure

Fortunately there are tools available that automate the complex calculations required to select the proper design for the application. These tools are defined in ASME PTC 19.3 TW-2010 which is an internationally recognized mechanical design standard yielding reliable thermowell guidance in a wide range if temperature measurement applications. It includes evaluation of stresses applied to barstock thermowells based on the design, material, mounting method and process conditions. The dominant factors in this consideration are fluid velocity and fluid density. Refer to the Documentation chapter 9.1 for a White Paper detailing these calculations.

Tip: It is very important to be aware that any process flow changes from such things as debottlenecking will have a potentially dramatic effect on the forces on the thermowell and a recalculation is required to ensure operation within safe limits.

The long awaited PTC 19.3 TW-2010 is a completely new standard that establishes the practical design considerations for thermowell installations in power and process piping. This code is an expanded version of the thermowell section contained in the PTC 19.3-1974, and incorporates the latest theory in the areas of natural frequency, Strouhal frequency, in-line resonance and stress evaluation. It includes

- Expanded coverage for thermowell geometry
- Natural frequency correction factors for mounting compliance, added fluid mass, and sensor mass
- Consideration for partial shielding from flow
- Intrinsic thermowell damping
- Steady state and dynamic stress evaluations
- Improved allowable fatigue limit definition.

Another factor is that the upcoming edition of ASME B31.3 will mandate ASME PTC 19.3TW where applicable.

Best Practices #9

Category:
Adverse Environmental and Electrical Noise Application

The Challenge:
The plant site is in an area with frequent lightning strikes and there are many large motors and their associated switchgear throughout the site. The transient voltages and surges in the plant wiring system are quite dramatic and have an adverse effect on our field instrumentation. In addition, there is high humidity and various chemical vapors in many of the plant areas where measurements are required.

Analysis and Solution:
The environmental conditions described require selecting a transmitter that has the capability to effectively protect the transmitter electronic assembly from exposure to these elements which are notorious for seeping into conduit runs and working their way towards the transmitter.

Single compartment housing transmitters have the electronics and the field connections within the same enclosure providing no protection for any contamination that may enter the housing. However, a dual compartment housing isolates the electronic assembly in one sealed compartment and has the terminal connections in a separate and isolated compartment thus greatly reducing the probability of exposure of the electronics to the adverse elements.

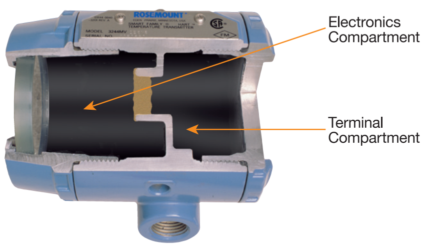


Figure 3.1.10.2a – Dual Compartment Housing

Specify a transmitter that has a dual compartment housing and also offers an internal transient suppression feature to protect the circuitry from the spikes and surges from the motors and the lightning. In addition, the transmitter should have excellent noise rejection capability for EMI and RFI generated by the heavy equipment, radios, antenna towers, and welders. Integrally mounting the transmitter with the sensor-thermowell assembly reduces exposure to electrical noise that would be picked up on remote mounted sensor cable.

Use of properly installed conduit seals, following proper shielding and grounding practices and specifying integral transient suppression modules for the transmitters all help to ensure maximum protection. Note that many external transient protection options do not offer hazardous area certification as does a dual compartment housing but may be suitable for mounting at the receiver end.

Figure 3.1.11.3a – Terminal Strip Mounted Transient Suppressor

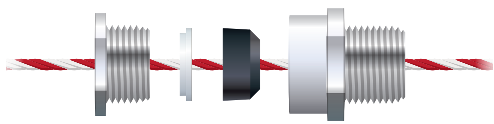


Figure 4.2.5.2.4a – Typical Conduit Seal

Best Practices #10

Category:
Local Display on Transmitter

The Challenge:
On selected transmitters we want to provide local indication of temperature and the output signal. Some transmitters will be mounted integrally with the sensor and others will be remote mounted on a pipe rack to facilitate operator viewing on routine rounds and for routine maintenance.

Analysis and Solution:
One Solution uses high end transmitters that typically offer an LCD option. Display options include engineering units (°F, °C, °R, °K, Ω, and mV), percent, and mA. The display can also be set to alternate between the engineering units / mA, Sensor 1 / Sensor 2, Sensor 1 / Sensor 2 / Average Temp, or Sensor 1 / Sensor 2 / Differential Temp.

Figure 3.1.3.5b – Remote Mounted Transmitter

The display is configurable to scroll through the selected values of measured temperature, range, engineering units, terminal temperature, device status, error messages and diagnostic messages. The meter displays the diagnostic error messages in order of priority with normal operating messages displayed last. The top line shows the error condition and the second line shows the cause for that condition. Configuration may be accomplished using a hand-held configurator, a laptop, through the DCS or through an asset management system.

Another solution is using transmitter models that also offer Local Operator Interface (LOI). The LOI can be used to locally configure the transmitter and change the display options.

Figure 3.1.11.2.2a – Head-mount Transmitter with LOI

If the measurement point is not easily accessible, remote mounting should be considered to ensure that the operator can easily view the meter face and conveniently perform maintenance tasks. The meter face may be rotated in 90º increments to meet viewing requirements. The location should be protected from physical and adverse environmental damage and not subjected to sprays or dripping.

Best Practices #11

Category:
Local Operator Interface

The Challenge:
Most of my transmitter installations will be in areas where electronic devices such as a hand-held configurator or a laptop computer are not available. Yet I want the field technicians to be able to change the configuration of these transmitters on site.

Analysis and Solution:
Specify a transmitter with a Local Operator Interface (LOI) option.

The LOI interface provides the ability for local configuration of the transmitter to make changes in real time without the requirement to use a laptop or field communicator. The buttons on the LOI are used to step through a configuration menu and select the various options.

Typical Configuration Menu Selections

- Sensor Type
- 4 mA Value
- 20 mA Value
- Engineering Units
- Damping
- Failure / Saturation Mode
- Line Voltage Filter Frequency

When the LOI is not being used for configuration, it displays the same information as the standard LCD including the user's choice of temperature, units, output value, etc.

As an alternative when using HART-enabled transmitters, the configuration procedures may be implemented using an asset management system.

Best Practices #12

Category:
Thermocouple Sensor Drift Monitoring

The Challenge:
Our high temperature annealing autoclave operation is experiencing quality issues due to inaccurate temperature control. Identification of the bad T/C measurement has been an ongoing problem that has resulted in considerable rework and reduced production. Identification of the drifting measurement quickly before it reaches a value that impacts product quality is an important cost control issue.

Analysis and Solution:
It is inevitable that a T/C will degrade and drift over time. The drift is even more rapid at higher temperatures.

One solution is to change over to dual element T/C assemblies and upgrade the transmitter to a model that offers a drift monitoring / alert option. The sensor drift alert feature notifies the control system of the degradation of a sensor that is causing its measurement signal to drift away from the actual value, thus decreasing the measurement integrity. By using two sensor inputs, the difference between the two sensors is monitored. When the difference becomes greater than a value entered by the user, the transmitter sends an alert to indicate a sensor drift condition.

This solution may be compromised by the fact that whatever causes the first element to drift will, more than likely, cause the other to drift sooner rather than later. This is referred to as common cause. The single transmitter is also a potential single point of failure.

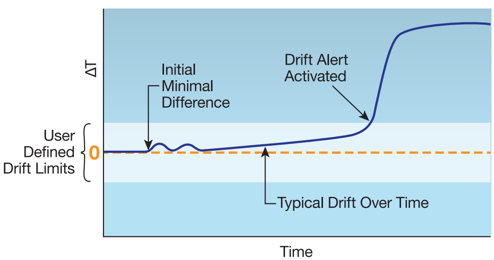


Figure 3.1.6.7a – Sensor Drift Alert Detects a Degrading Sensor

Another solution is to use two separate T/C assemblies each with a different T/C element design and/or T/C type. As above, both would be connected to the same dual input transmitter with the drift monitoring feature. The assumption is that the common cause factor is somewhat reduced by adding diverse sensors but a single transmitter failure remains as a potential problem.

A third solution is using two T/C assemblies as in the above solution coupled with two independent transmitters. This solution has the highest cost but provides the greatest potential for a high integrity measurement. An economic analysis should be made to balance the cost of a poor or lost measurement including the cost of lost production (Typically very large) vs. the instrumentation, installation and maintenance of the chosen system (known as cost-benefit analysis).

Best Practices #13

Category:
Minimum-Maximum Tracking for Quality Assurance

The Challenge:
The quality assurance department requires verification that the product was not exposed to temperatures outside of the specified curing range. They require the minimum and maximum temperatures of the curing cycle be provided.

Analysis and Solution:
One solution is to specify a transmitter with HART protocol that offers a Minimum-Maximum Tracking feature that can be configured using a hand-held field communicator, asset management system, or other communicator to record the minimum and maximum temperatures obtained since the last reset.

Another solution is that on some transmitters using FOUNDATION fieldbus, the Minimum-Maximum Tracking can be configured to record lifetime minimum and maximum temperatures with time and date stamps.

A third solution is to bring the temperature measurements into the BPCS/DCS and use logic to set and reset batch min/max temps and ensure that the temperatures, resets and required points are recorded in the historian for trending and cross correlation.

Best Practices #14

Category:
Remote Pipeline Temperature Measurement

The Challenge:
Operations have requested that a measurement of pipeline temperature indication be provided to the DCS. However, the pipeline is in a remote part of the plant site separated from the control room by several roadways and a railroad siding. The cost of running cable over or under those obstructions is very expensive and time consuming.

Analysis and Solution:
Wireless transmitters provide for the transmission of the measurement signal over distances up to 1/2 mile. Refer to the Transmitter chapter 3.1 for complete transmitter details.

Specify a temperature measurement system using a spring loaded RTD assembled with an appropriate thermowell to meet the installation requirements. Refer to the “Selecting and Installing Your Temperature Components” section 4.2 for guidance.

Another solution for applications where pipe penetration is not possible or practical is using a clamp-on sensor with the wireless transmitter.

Tip: Another application where this concept is very effective is for ambient temperature monitoring at various points around a plant site. Wireless transmitters provide a measurement with very little impact on the plant infrastructure and at minimal cost.

Figure 3.2.3.5.2b – Surface Mount Sensor with Pipe Clamp Mounting

Best Practices #15

Category:
Excessive Measurement Drift Error

The Challenge:
We have had many cases of off-spec product production due to temperature measurement inaccuracy. We installed a new smart temperature transmitter but the problem continues. We are using high quality three-wire RTDs connected to a remote mounted transmitter.

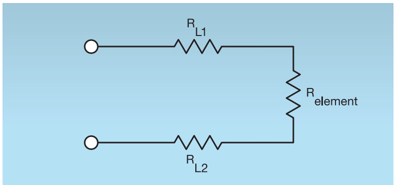
Analysis and Solution:
Even though a smart temperature transmitter compensates for lead resistance for three-wire RTDs, the compensation assumes that the leads are of equal resistance.

In the real world however this is never the case. There is always some difference in resistance of the leads and extension wire due to wire manufacturing tolerances, differing amounts of corrosion under terminal screws, work hardening by bending in connection heads etc. that all contribute to some degree to the leads having different resistances.

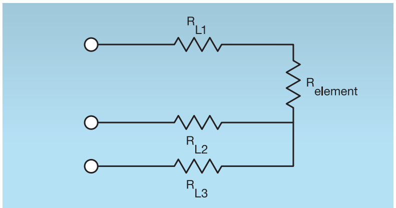
Just a 1Ω difference can cause an error of 2.5 °C and this error will vary unpredictably with changes in temperature, moisture or corrosive environmental variation. Differences of several ohms are not uncommon in field installations.

The solution is to replace the 3-wire RTDs with 4-wire RTDs. The transmitter configured for 4-wire measurement passes a very small constant current through the sensor element using two of the leads and measures the voltage developed across the sensor with a high precision voltage measurement circuit using the other two leads. Lead resistance differences are of no consequence and an accurate and stable measurement is provided.

Note: All leading transmitters accept either 3 or 4-wire RTD sensor inputs so there is no need to replace the transmitter for this upgrade.



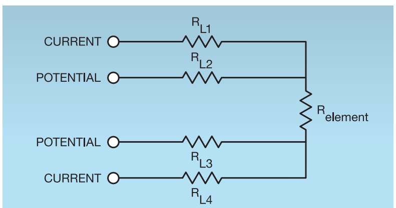
$$R_{measured} = R_{L1} + R_{element} + R_{L2}$$



$$R_{measured} = R_{L1} + R_{element} + R_{L2} - [R_{L2} + R_{L3}]$$

$$= R_{L1} + R_{element} - R_{L3}$$

$$= R_{element} \quad (\text{If } R_{L1} = R_{L3})$$



$$R_{measured} = R_{element}$$

Figure 3.2.3.1.3.1b – Two-, Three-, Four-Wire RTDs with Equations

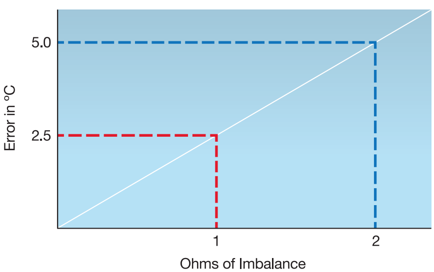


Figure 3.2.3.1.3.1c – Lead Imbalance vs. Error for 3-Wire RTD

Best Practices #16

Category:
Remote Tank Temperature Profile

The Challenge:
On a curing tank located in a remote area of the plant it is important for product quality to have a uniform temperature from top to bottom. We want to monitor the temperature profile to assure consistency within an allowable range. We have determined that 10 to 12 RTD sensors will be needed to establish this profile. The limited project budget demands that a very cost effective solution be found.

Analysis and Solution:
It is clear that individually mounted transmitters that are individually cabled to the control room could certainly do the job. However, a much more cost effective solution is to use multichannel transmitters that can operate wirelessly. This choice minimizes transmitter costs vs. individual units and has the added benefit of using the Wireless HART protocol that will save considerably on purchase and installation of long cable runs that would be required for the individual transmitters.

Using a 4-channel high density transmitter featuring Wireless HART protocol provides a very cost effective solution. Three units can be mounted on or near the tank to minimize the length of sensor leads.

Fully compatible with any WirelessHART™ network, the wireless solution provides the same rich diagnostic data and reliable performance as other devices in the HART smart wireless family and is compatible with existing HART configuration tools and asset management systems. It accepts four individually configured sensor inputs and continuously monitors measurement integrity. The device is self-powered and utilizes technology to provide an intrinsically safe power module with long battery life.

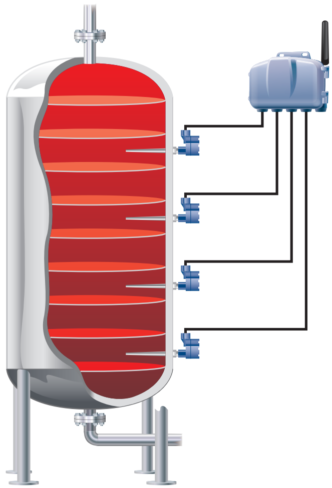


Figure 3.1.2.3c – Temperature Profiling a Reactor

Best Practices #17

Category:
Add-On Measurement without a Thermowell

The Challenge:
Process Engineering has requested a temperature measurement in a pipeline in a remote area of our plant site that is associated with a continuously running process. They want the measurement now and any shutdown of the process to install a thermowell cannot happen for many months. We want a temporary solution to get us through to the next scheduled process shutdown where a long term solution can be implemented with the installation of a thermowell-sensor assembly. We want to reuse the same transmitter at that time.

Analysis and Solution:
Fortunately this problem has a reasonable solution although with some caveats. There is a whole family of surface mounting sensors that can mount a sensor externally to your pipe. There are contact block / pad where the sensor is built into a block of metal that is fastened to the surface by bolts, screws, clamps, magnets or welds. The magnetic-mount uses one or more magnets to hold a tip sensitive T/C sensor against the surface of the vessel or pipe. This style is easily moved from place to place and accommodates irregular surfaces. For pipeline applications a pipe clamp-on style with an RTD sensor is usually the best solution for ease of installation combined with better response characteristics than some of the other styles.

Surface measurement is only as reliable as the temperature on the surface of the pipe or vessel. In general, the goal is to maximize heat conduction from the pipe or vessel surface to the sensing element. Good thermal contact is necessary as well as using thermal insulation to minimize the loss of heat energy from the surface of the pipe to its surroundings. The insulation should cover the sensor and the lead wires for some distance to minimize any conduction heat losses to the leads. This helps to assure that that the sensor is at, or as close as possible to, the actual surface temperature of the pipe which is assumed to be at the process fluid temperature. Process fluid flow rate and rate of temperature change significantly influence this assumption. Differing thermal coefficients of expansion of the pipe and the mounting assembly must also be considered to minimize stress to the sensor that would degrade the measurement or even destroy the sensor.

When long distances are involved for the measurement point to the control system, a wireless transmitter mounted near the pipe clamp sensor is a cost effective solution compared to long cable runs. Of course this same transmitter can later be used with the sensor installed in the future thermowell upgrade to provide improved performance and accuracy.

Figure 3.2.3.5.2b – Surface Mount Sensors - Pipe Clamp

Best Practices # 18

Temperature Measurement Engineering

Category:
EMI and Surge Withstand Concerns

The Challenge:
A global company has plant sites in North America, Europe, Asia, and South America. There are some plants with heavy equipment that generates significant Electromagnetic Interference (EMI), the older plants have questionable grounding schemes that often affect measurement integrity and others have a history of power surges from frequent lightning strikes. Our older generation transmitters are quite susceptible to these adverse conditions and are adversely affecting temperature control causing repeated process upsets and unscheduled shutdowns.

Analysis and Solution:
A suggested solution is to upgrade these transmitters and standardize on the temperature transmitters used on a corporate global basis. The most efficient and therefore cost effective solution is to select a single vendor solution that offers the appropriate options that will provide immunity to the adverse conditions found in many of these plants and assure that they can comply with applicable codes and approvals in the various countries. Select a supplier that can provide one model series that will meet these needs with global availability. This path will save time and money by standardizing on one specification, larger quantity ordering, unified inventory, common installation practices, uniform maintenance procedures and standardized operator and instrument technician training.

Some of these options that address the problem areas include:

- Full input-output galvanic isolation that will prevent ground loops that can result from improper grounding of field equipment and that can dramatically affect measurement integrity. An isolated transmitter also has provision to block both normal mode and common mode voltages that may inadvertently come in contact with the measurement circuit.
- For high EMI environments that can cause intermittent sensor signals to the transmitter, an open sensor hold-off option detects a false open sensor condition and performs calculations to determine when the transmitter should send an indication to the control system. For example, the transmitter determines if an open sensor event has actually occurred or a high voltage transient event, such as lightning or electrostatic discharge, has caused a false open sensor condition. To avoid an unnecessary alarm and possible process control disruption, the established temperature value continues to be sent until the transmitter identifies the true source of the condition and takes the appropriate failure action only upon a verified sensor failure.

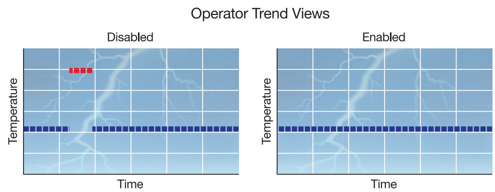


Figure 3.1.6.2a – Open Sensor Holdoff Option

- For applications exposed to severe vibration or significant electrical surges the Intermittent Sensor Detection feature recognizes intermittent sensor signals from conditions like high vibration or a noisy environment that may cause incorrect intermittent temperature readings and rejects them. By disregarding these temperature spikes, sensor signal interruption is prevented and the last known reliable temperature continues to be transmitted thus saving a potential process upset or trip condition.
- The vendor should offer a complete capability to meet agency approval requirements in most countries for explosion proof, watertight, Intrinsically Safe and also assure that Electromagnetic Compliance (EMC) requirements are met.

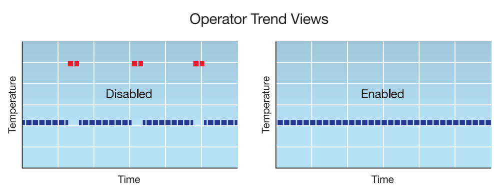


Figure 3.1.6.3a – Intermittent Sensor Option

Best Practices #19

Temperature Measurement Engineering

Category:
Thermal EMF Compensation

The Challenge:
In an RTD there is a junction inherent in the sensor probe wherein copper lead wires are welded to the platinum or nickel sensor wire. There may also be other junctions in the measurement loop. Every connection made with dissimilar metals creates an unwanted thermocouple in the measurement circuit. Each of these unwanted thermocouples generates an error voltage that varies with temperature gradients in the system. These can be on the order of many microvolts that can cause significant errors in RTD, strain gauge, and low-ohms measurements.

How do we account for this dynamic error in our measurement?

Analysis and Solution:
EMF Compensation monitors RTD sensor loops and filters out small voltages, allowing the transmitter to provide sensor measurements that are unaffected by thermal EMFs, resulting in a more reliable temperature measurement.

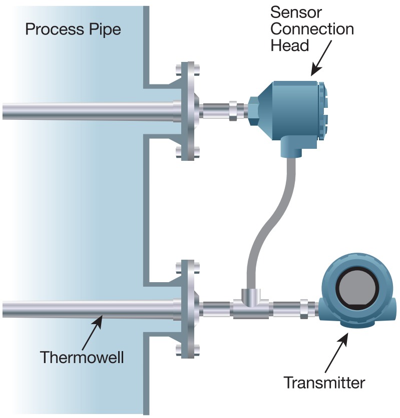
Best Practices #20

Category:
Efficient Chiller Control

The Challenge:
The chiller pump speed is controlled based on the differential temperature of the incoming vs. the outgoing chilled water temperature. An accurate measurement has a direct effect on energy usage of the chiller and product quality in the client process. An error on the low side could cause excess wasted cooling while an error on the high side provides inadequate cooling to the downstream process resulting in quality issues. Small errors can have major consequences.

Analysis and Solution:
There are several possible solutions for this application listed in order of preference:

- The two RTD sensors could be connected to a single transmitter offering a dual input differential temperature option. The output representing the differential temperature is then connected to the DCS for control implementation.
  - Specify a transmitter that offers a dual input capability and can be configured to compute the differential of the two RTD inputs as the output to the DCS.
  - When used with two High quality RTD assemblies, each with calibration data, a highly accurate and stable differential measurement can be made
  - The transmitters may be configured to drive to a known value upon failure of a sensor such that control can go to a fail-safe value.



Dual Sensor Application with Integrally Mounted transmitter and remote sensor

- Two individual temperature transmitters with either integral or remote RTD sensor assemblies could be installed and connected to the DCS and again the differential is calculated and control implemented.
  - While this solution will produce excellent results, it has the associated cost of a second transmitter and its associated installation and maintenance costs as well as programming costs in the DCS
- Two RTD sensors could be installed and directly connected to the DCS where the differential could be calculated and control implemented.
  - While this option appears to be the simplest and most robust since there is only one electronic device, there are costs involved with running multi-conductor sensor cables

– Sensor signals are much more susceptible to EMI and RFI causing likely unpredictable errors than are 4-20 mA signals

– Accuracy is not as good as using a transmitter

– There are DCS programming costs.

Best Practices #21

Category:
Fast Response and High Precision Requirement

The Challenge:
The process in one of our reactor vessels is very dynamic as the vessel reaches the critical reaction temperature of 125 °C ± 0.2 °C (257 °F) with rapidly rising process temperature. If the temperature is not closely controlled at this point, off-spec product will result with an enormous cost of reprocessing and lost production time. We need a very fast responding and accurate temperature measurement system.

Analysis and Solution:
A thin film spring loaded style of RTD matched to a high performance remote mounted transmitter is going to provide both precision of measurement and fast response. Remote mounting the transmitter eliminates the potential transmitter over-temperature exposure of integral mounting on a high temperature vessel.

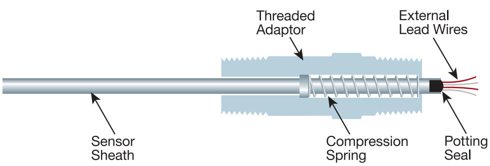


Figure 3.2.3.1.2b – Spring Loaded Sensor

However, the limiting factor for speed of response is the time lag associated with the thermowell. It is intuitively clear that the larger the mass that needs to respond to the changing temperature, the longer it will take to reflect the change to the transmitter. Therefore the goal is to minimize the associated mass of the sensor-thermowell assembly and ensure that the sensor is spring loaded and snug fitting in the thermowell. Use of a thermally conductive fluid between the sensor and the well will improve the speed of response as well.

Figure 3.1.3.5b – Remote Mounted Transmitter with LCD

A stepped design thermowell will provide the fastest response as compared to straight and tapered designs of the same root diameter. In selecting the thermowell consideration must be given to the material selection, the mounting style, the pressure rating and potential for flow induced vortex shedding vibration. A careful wake frequency analysis must be made to ensure consideration of these factors and compliance with codes and recommended practices. Detailed guidance and procedures are spelled out in ASME PTC 19.3 TW 2010 which is described in detail in Chapter 3.3 Temperature Measurement Basics. See also the Thermowell Calculations white paper in section 9.1.

For low pressure / low flow applications, a thin wall protection tube may offer a faster response than a barstock type of well.

For optimal performance, a factory assembled system of sensor and transmitter complete with sensor-transmitter matching using the Callendar van Dusen constants of the sensor (CVD) will ensure the best possible solution. A top of the line transmitter from a leading manufacturer offers the ultimate in performance and features for such applications.

With a cost-benefit consideration, two complete transmitter-sensor assemblies may easily be justified.

For an even more robust system three measurements could be taken and the DCS could select the middle value of the three as the “good” signal. See the Analysis and Solution for Best Practices #4 and #20 for more detail on this solution.

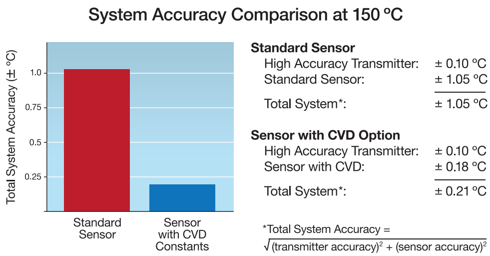


Figure 3.1.4.3.3a – Sensor – Transmitter Matching

Best Practices #22

Category:
Safety Certified Transmitters

The Challenge:
Our new reactor includes a Safety Instrumented System (SIS) that will have several temperature loops that will require use of safety certified transmitters. Most of the transmitters are associated with safety functions that have been designated as Safety Integrity Level (SIL) 1 and the balance of them are SIL 2.

The Basic Process Control System (BPCS) also has several temperature measurements that do not require any certification. For purposes of standardization we would like to use the same model instruments wherever possible.

Analysis and Solution:
A transmitter to be used for a safety function in an SIS must meet certain design and performance criteria and be certified for use in accordance with IEC 61508 or IEC 61511.

Specify a transmitter that carries the required safety certification as specified for this project. A typical certification document states that "the transmitter is certified to IEC61508 for single transmitter use in Safety Instrumented Systems up to SIL 2 and redundant transmitter use in Safety Instrumented Systems up to SIL 3. The software is suitable for SIL 3 application." There will be a yellow Safety Tag on the transmitter.

Although there is a "proven-in-use" clause in the IEC 61511 standard that allows use of non-certified devices in safety functions, it carries the burden of laborious record keeping of failure related information for a large number of installations of the same model in similar applications over long time periods. Use in safety related systems is at the owner's discretion.

Best practice indicates that designing your system around an IEC 61508 certified instrument avoids the laborious and expensive record keeping for proven-in-use devices. It should be noted that many vendors offer the same basic product for both process control and safety applications. There is benefit to using the same models as are used in the basic process control system (BPCS) to take advantage of the history of installation and operation knowledge that already exists as well as reducing spare parts inventory.

A certified transmitter with a Safe Failure Fraction (SFF) of 90 or above allows using only a single transmitter to meet the SIL 2 requirements. However, a Safety Instrumented Function (SIF) is assigned a Safety Integrity Level SIL) during risk analysis. All of the components of the SIF are considered together in performing a SIL compliance calculation. The result is that, even though the transmitter is certified up to SIL 2 as a single device, the limitations of the sensor and the final control element (usually a valve) typically demand a redundant configuration of 1 out of 2 (1oo2) or 2oo2 to meet a SIL 2 requirement. Therefore, most safety engineers follow the path of using two transmitters to provide a layer of hardware redundancy for fault tolerance.

A best practice consideration is to specify remote mounted transmitters. The separately mounted sensor assemblies will be easy to remove from service for testing greatly facilitating and improving the proof testing of the sensor assemblies.

Best Practices #23

Category:
Temperature Profile of a Reactor Vessel

The Challenge:
Some reactors and distillation columns rely heavily on maintaining a specific temperature profile. To achieve tight temperature control requires continuously monitoring the temperature of specific reactor tubes to identify hotspots that could lead to off spec production. There are to be well over 100 measurements.

Analysis and Solution:
One option is to individually mount transmitters as these can provide highly reliable measurements to the control system to address the hotspot identification issue. However the cost of purchase, installation and maintenance will be significant.

A much more cost effective solution is to use high density multichannel transmitters. There are models that use WirelessHART™ technology and other models that incorporate FOUNDATION™ fieldbus. Some fieldbus models have a measurement validation diagnostic available that provides insight into the process and can identify measurement abnormalities like sensor degradation, drifting, excess rate of change, etc. before they become a major issue, saving the time and money associated with unscheduled process shutdowns and helping to run the process more efficiently.

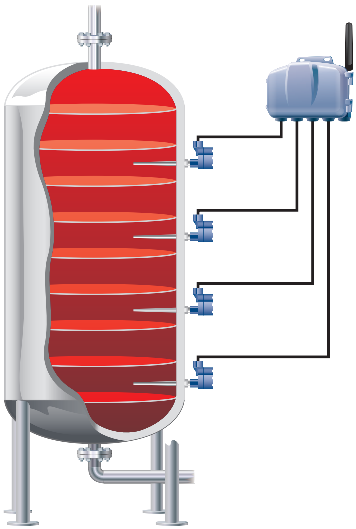
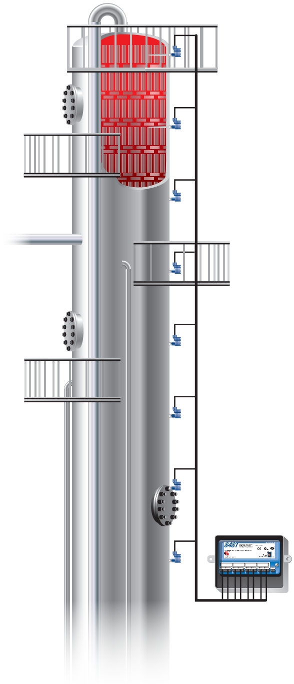


Figure 3.1.2.3c – Temperature Profiling a Reactor - WirelessHART™ Solution

Both solutions can be very cost effective as compared to individual hard wired transmitters however; the FOUNDATION™ fieldbus approach is more widely accepted for continuous control applications.



Foundation Fieldbus Solution

Depending on the temperature range, plant preference, and the degree of precision required, T/Cs or RTDs could be selected. T/Cs will provide a less accurate measurement and are more subject to drifting and EMI. Refer to section 4.2.3.1- Comparison of RTD vs. T/C for a more detailed discussion.

Best Practices #24

Category:
Custody Transfer in Accordance with Measurement Instruments Directive (MID) for Europe

The Challenge:
In addition to the measurement precision typically required for a custody transfer application, the system must also be certified to the European Union Measurement Instruments Directive for custody transfer of liquids and gases.

Additional conditions and requirements include:

- The system must be supplied as a preassembled, tested, calibrated and certified assembly from the vendor
- The potential cost savings associated with a highly accurate temperature compensation demand that this system provides the best accuracy and stability possible

Analysis and Solution:
The temperature system selected must have been certified to meet the MID for custody transfer of liquids and gases.

Specify that the system is to be supplied as a preassembled, tested, calibrated and certified system with sensor-transmitter matching using the sensor's Callendar-van Dusen constants. The matching process will provide an accuracy of about ± 0.2 °C or better.

Install, commission, and operate the system in accordance with plant policies and procedures.

Best Practices #25

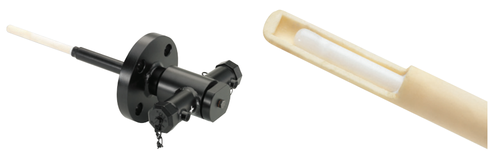
Category:
High Temperature - High Pressure Gasification

The Challenge:
The gasification process in the oil and gas, refining, and power industries impose difficult conditions for the measurement instrumentation with temperatures as high as 1800 °C (3272 °F), pressure up to 65 bar (943 PSIG), and process generated contamination that poisons thermocouples. (Corrosive components in the atmosphere may permeate the T/C sensor sheath and cause rapid deterioration of the T/C junction with related degraded accuracy.) Frequent thermocouple failures require an unplanned shutdown for replacement with the associated loss of production availability and resulting higher cost of operation. In some applications damage occurs to refractory linings incurring further delays and costs. There are also safety and environmental issues that result from leakage of flammable and toxic emissions from these failed thermocouples. Potential consequences include damage to equipment, personal injury, OSHA infractions, and EPA violations.

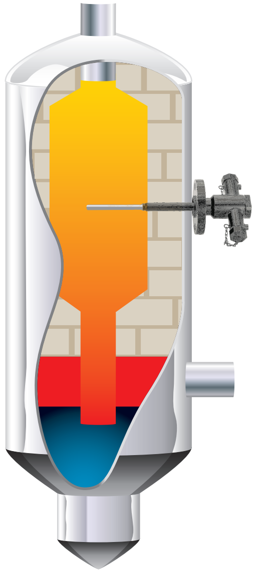
Analysis and Solution:
Rosemount is one of the very few manufacturers that offer a high temperature-high pressure thermocouple solution called the "Sapphire High Temperature Sensor".

The Sapphire sensor is designed to withstand temperatures up to 1800 °C and pressure up to 65 bar (943 PSIG). The gas-tight sapphire protection tube is hermetically sealed to its support bushing using a patented process to protect the T/C sensor from poisoning from the destructive atmosphere within the gasifier thereby extending its useful life dramatically – often by as much as two or three to one. Additionally it has a dual redundant pressure seal to eliminate any toxic or corrosive leakage. The process flange and the connection housings are optionally available as a forged assembly to address leakage concerns of hydrogen containing gases.

The thermocouple degradation feature continually monitors the resistance of the thermocouple loop. If the resistance goes above a certain designated trigger level, an alert is sent suggesting sensor replacement. The degrading thermocouple can be caused by wire thinning, sensor breakdown, moisture intrusion or corrosion and can be an indication of an eventual sensor failure. Identifying this degraded condition prior to a complete T/C failure could prevent an unscheduled process trip and save an expensive unscheduled shutdown.



Sapphire High Temperature and High Pressure Sensor Assembly



Sapphire High Temperature and High Pressure

Best Practices #26

Category:
Chemical Process Fractionation Temperature Gradient

The Challenge:
To optimize column throughput and still maintain product quality and purity requires monitoring and control the temperature gradient in a product distillation column. Close temperature control optimizes the product quality and throughput at each of the cut points where the various components or fractions are drawn off. However, it is often impractical from a cost point of view to penetrate the side of the column for each measurement and a top penetration will be used for all 12 required measurements.

Analysis and Solution:
A multipoint RTD sensor is a very effective solution for this application. It uses a single tank penetration and has multiple RTD sensors in a single thermowell. A radial spring design provides spring loading of each sensor against the inner wall of the thermowell for optimal response. The assembly will have many four-wire RTDs spaced at user-specified points over its length. (Maximum length is 10,000 mm / 33 ft)

It can be supplied with a thermowell or can be fitted into an existing thermowell with proper bore diameter and internal finish.

Multipoint Sensor

There are several alternatives for transmitters with the highest performance offered by top-of-the-line individual transmitters from major manufacturers. Multipoint transmitters are another alternative.

Figure 3.1.10.3b – Multichannel Rail-Mount Transmitters

Since the measurements will be in a chemical processing unit, it is expected that the area classification will most likely require explosion proof certification.

Best Practices # 27

Temperature Measurement Engineering

Category:
Smoke Stack Flare Monitoring

The Challenge:
Our vent stack uses a continuously burning pilot flame to ensure that any combustibles exiting the stack are flared off. If the flare fails, combustible and potentially toxic fumes could be exhausted causing a dangerous condition in the area and potentially violating EPA regulations. We need to install a high reliability pilot flame temperature measurement system that can be locally monitored at the base of

the stack and that will transmit a reliable signal back to our control room. Due to the difficulty of sensor replacement on this tall stack, we want to consider sensor redundancy.

Analysis and Solution:
The challenging conditions for this application suggest that a temperature system with a remote mount transmitter mounted at the base of the stack with an LCD indicating option would provide a very effective solution. This configuration removes the transmitter from the adverse heat and contamination at the stack exit and facilitates maintenance.

With the LCD the area operator can verify that the pilot temperature is within range and also see any diagnostic alerts.

The flame monitoring sensor should be specified as a dual element isolated T/C assembly that will provide the redundancy needed for a longer service life. Refer to the Sensors Chapter, Section 3.2.4.3.1 for more information.

The transmitter should be specified with a hot back-up feature. The Hot Backup® feature is the ability of the transmitter to automatically switch the transmitter input from the primary sensor to the secondary sensor should the primary sensor fail. This prevents a process disruption due to the failure of the primary sensor. A maintenance alert is also generated to notify operators that a sensor has failed and hot backup is active. In this way, a critical temperature measurement is not lost, and pilot flame integrity is assured.

To account for the potential for an intermittent sensor signal due to wind gusts blowing the pilot flame away from the sensor, the transient filtering option should be activated in the transmitter.

Figure 3.1.3.5b – Remote Mounted Transmitter with LCD

Best Practices #28

Temperature Measurement Engineering

Category:
Fluid Catalytic Cracker (FCC) Temperature Profile

The Challenge:
In petroleum refining, cracking is the process whereby complex organic molecules are broken down into simpler molecules such as light hydrocarbons. The rate of cracking and the end products are strongly dependent on the temperature and presence of catalysts. Optimum catalyst life and product throughput are heavily dependent on maintaining a consistent temperature profile over the height of the vessel and eliminating hot spots. Our analysis indicates the requirement for 50 measurements evenly spread over the height of the 18.3 m (60 ft) column.

It is impractical to make penetrations through the side of the column so that all measurements must be made from the top of the vessel where a thermowell was installed at the time of construction.

Analysis and Solution:
The application as described is a classic case that has a cost and performance effective solution by using a multipoint thermocouple probe assembly. There are models available that can accommodate up to 60 sensing elements that are ideal for such applications. For lengths over about 10m (33 ft) they are provided in a flexible design that may be coiled for shipping and to assist in installation.

The T/C signals can be connected directly to the control system or used with either single channel transmitters or multipoint transmitters. Optimal performance is always ensured by using a transmitter. Direct connected sensors using the required special extension cables are much more subject to signal degradation and deterioration than the robust signals from transmitters and are often more expensive to purchase, install and maintain. Refer to the Engineering and Design Chapter, Section 4.3.4 for more details.

Best Practices #29

Temperature Measurement Engineering

Category:
Electrowinning and Electrorefining of Metals

The Challenge:
The processes of electrowinning and electrorefining both rely on close control of bath temperature and of the voltage applied to the electrodes for optimization of plating time and energy usage efficiency.

A processing room may have hundreds of processing tanks spread over a large area. Each tank requires a temperature and a voltage measurement. For Electrowinning the measured voltage is in the range of 0-10 Volts and for Electrorefining the range is 1-1000 mV.

The environment in the room is very acidic making corrosion of cables and conduits an expensive maintenance issue. There are also strong electromagnetic fields around the tanks that can influence electronic instruments.

Analysis and Solution:
Not all wireless solutions are created equally. There are products using versions of the 802.11 wireless standard and others using proprietary protocols that are susceptible to the kinds of interference prevalent at electrowinning and electrorefining facilities and therefore have performance issues.

However, multichannel transmitters using the WirelessHART™ protocol are far more robust and will function reliably under the adverse conditions described.

WirelessHART™ is an open-standard wireless networking technology developed to complement the existing HART standard and is in conformance with International standard IEC 62591 WirelessHART Architecture.

One four channel transmitter can accept either a 0-1 V or a 0-10V voltage signal and a temperature sensor signal from each of two tanks and transmit the signal reliably to the control room from the tank room.

The self healing mesh architecture with channel hoping and redundant paths easily compensates for reflected signals by the cranes or moving stacks of cathodes.

The wireless solution eliminates the need for the cable trays, conduits and high maintenance costs associated with using individual transmitters.

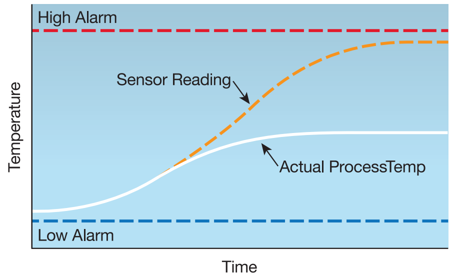
Best Practices #30

Temperature Measurement Engineering

Category:
Hydrocracker False Temperature Reading Control Issues

The Challenge:
The hydrocracker unit has a high temperature and high pressure exothermic reaction that is adversely affected by invalid temperature measurement readings. As the thermocouples (T/C) degrade over time false high readings occur which often trigger an unnecessary nuisance shutdown.

Additionally, the readings are often on scale and appear to be good when in fact they are invalid due to drift or noise interference.



It is also important to detect rapidly increasing temperatures that indicate a runaway reaction such that it may be contained.

Other invalid measurement issues are:

- Inefficient energy usage
  - Wasteful heating/cooling system responses to an inaccurate temperature
- Decreased product yield and throughput
  - Inaccurate temperature can lead to less than optimal reaction conditions
- Off spec product
  - Inaccurate temperature in extremely sensitive process can lead to unusable product/ waste
- Unnecessary process shutdown
  - False high temperature reading can trigger a nuisance shutdown alarm
- Unsafe process conditions
  - False low readings cause the process to run hotter than you think it is

- There are always safety issues associated with unnecessary shutdown caused by false high readings

Analysis and Solution:
Transmitter technology is continually evolving and new options and features become available to address issues such as those described in the challenge above.

One of the newer features is a measurement validation diagnostic available on some top-of-the-line transmitters that incorporates an algorithm to evaluate the variation in the raw signal input to the transmitter to detect significant changes in the signal trend that may indicate a failing or degrading sensor or connection.

This evaluation helps to identify degraded sensors that can produce on scale readings that are inaccurate prior to actual sensor failure.

The diagnostic can also detect abnormally fast process changes by calculating change in temperature divided by change in time to identify a potential runaway reaction scenario and contain it before any damage can be done.

By continually validating the measurements the control system may be configured to reject those that are invalid and thus maintain reactor control.

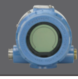
By identifying sensors that are degrading before they fail, preventative maintenance can be performed without interrupting the process.

7

Rosemount Temperature Products

TOPIC PAGE

7.1 – Transmitters

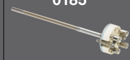
Features		3144P 	648 	644 	248 	848T 
Performance		Superior	Good	Good	Basic	Good
Input	Sensor Inputs	2	1	2	1	8
	Inputs Supported	RTD, T/C, Ohm, mV	RTD, T/C, Ohm, mV	RTD, T/C, Ohm, mV	RTD, T/C, Ohm, mV	RTD, T/C, Ohm, mV, 0-10V, 4-20mA
Outputs	HART 4-20mA	●	○	●	●	○
	FOUNDATION Fieldbus	●	○	●	○	●
	Profibus	○	○	●	○	○
	WirelessHART	○	●	○	●	●
Mounting Style	Field-Mount	●	●	●	●	●
	Head-Mount	○	○	●	●	○
	Rail-Mount	○	○	●	●	●
Housing Style	Dual Compartment	●	●	○	●	○
	Single Compartment	○	○	●	●	●
Displays	Standard	●	●	●	○	○
	Local Operator Interface	○	○	●	○	○
Safety	SIS Safety-Certified to IEC 61508	●	○	●	○	○
Transient	Integral Transient Protection	●	○	●	○	●

KEY: ● Availaible ○ Not available

Features		3144P 	648 	644 	248 	848T 
Intelligent Filtering and Diagnostics Features	Hot Backup® Feature	●	○	●	○	○
	Sensor Drift Alert	●	○	●	○	○
	T/C Degradation	●	○	●	○	○
	Measurement Validation	○	○	○	○	●
	Transmitter – Sensor Matching with CVD	●	●	●	●	○
	EMF Compensation	●	○	●	●	●
	Diagnostics Log	●	○	●	○	○
	Minimum and Maximum Tracking	●	○	●	○	○
	Configurable Process Alerts	●	●	●	○	●
	Differential Temperature	●	○	●	○	●
	Average Temperature	●	○	●	○	●
	Open / Short Sensor	●	●	●	●	●
	Open Sensor Holdoff	●	●	●	●	●
	Transient Filtering	●	●	●	●	●
	Line Voltage Filer	●	●	●	●	●

KEY: ● Availaible ○ Not available

7.2 – Sensors and Thermowells

Features		0065 	0068 	0078 	0185 	0183 
Description		RTD Sensor	RTD Sensor	RTD Sensor	Thermocouple Sensor	Thermocouple Sensor
Temperature Range	Temperature Limits	-196 to 600°C (-321 to 1112°F)	-50 to 400°C (-58 to 752°F)	-200 to 600°C (-328 to 1112°F)	-40 to 1000°C (-40 to 1832°F)	-180 to 1150°C (-292 to 2102°F)
Thermocouple Type	B	○	○	○	○	○
	E	○	○	○	●	●
	J	○	○	○	●	●
	K	○	○	○	●	●
	N	○	○	○	●	○
	R	○	○	○	○	○
	S	○	○	○	○	○
	T	○	○	○	●	●
RTD Element Design	Wire Wound	●	○	●	○	○
	Thin Film	●	●	○	○	○
Number of Sensor Elements	Single	●	●	●	●	●
	Dual	●	○	●	●	●
Accuracy	Class A	●	○	●	○	○
	Class B	●	●	●	○	○
	CVD Available	●	●	●	○	○
	Class 1	○	○	○	●	○
	Class 2	○	○	○	○	○
	Special Limits of Error	○	○	○	○	●
	Standard Limits of Error	○	○	○	○	○
Sensor Styles	DIN Plate	●	○	○	●	○
	Spring-loaded Adapter	●	●	●	●	●
	Welded Adapter	○	●	●	○	●
	Bayonet	○	●	●	○	●
	Adjustable Fitting	○	●	●	○	●
	Capsule Only	○	●	●	○	●
	Sanitary Tri-Clamp	○	○	○	○	○
Thermowell	Barstock	○	○	○	○	○
	Integral Protection Tube	●	○	○	●	○
	Integral Barstock Thermowell	●	●	●	●	●
Stem Designs	Straight	●	●	●	●	●
	Tapered	●	●	●	●	●
	Stepped	●	●	●	●	●
	Straight Tapered Straight	○	○	○	○	○
Thermowell Material	316 Stainless Steel	●	●	●	●	●
	304 Stainless Steel	●	●	●	●	●
	Titanium	●	●	●	●	●
	Carbon Steel	●	●	●	●	●
	Alloy 20	●	●	●	●	●
	Alloy 400	●	●	●	●	●
	Alloy 600	●	●	●	●	●
	304 Stainless Steel with Teflon Coating	●	●	●	●	●
Mounting Configurations	Flange	●	●	●	●	●
	Welded	●	●	●	●	●
	Threaded	●	●	●	●	●
Pipe Clamp Material	304 Stainless Steel	○	○	○	○	○
	Duplex	○	○	○	○	○

KEY: ● Availaible ○ Not available

Sapphire, Multipoint, and Surface Sensor designs are also Available

Features		1067 	1057/1099 	58C	65Q	68Q
Description		RTD or Thermocouple	Precious Metal Thermocouple Sensor	Cutable RTD Sensor	Sanitary RTD Sensor	Sanitary RTD Sensor
Temperature Range	Temperature Limits	-196 to 1000°C (-321 to 1832°F)	-40 to 1800°C (-40 to 3272°F)	-50 to 200°C (-58 to 392°F)	-50 to 450°C (-58 to 842°F)	-50 to 200°C (-58 to 392°F)
Thermocouple Type	B	○	●	○	○	○
	E	●	○	○	○	○
	J	●	○	○	○	○
	K	●	●	○	○	○
	N	●	○	○	○	○
	R	●	●	○	○	○
	S	●	●	○	○	○
	T	●	○	○	○	○
RTD Elemental Design	Wire Wound	●	○	○	○	○
	Thin Film	○	○	●	●	●
Number of Sensor Elements	Single	●	●	●	●	●
	Dual	●	●	○	●	●
Accuracy	Class A	●	○	○	●	○
	Class B	●	○	●	●	●
	CVD Available	●	○	○	●	●
	Class 1	●	●	○	○	○
	Class 2	○	●	○	○	○
	Special Limits of Error	●	○	○	○	○
	Standard Limits of Error	○	○	○	○	○
Sensor Styles	DIN Plate	●	○	○	●	○
	Spring-loaded Adapter	○	○	○	○	○
	Welded Adapter	○	○	○	○	○
	Bayonet	○	○	○	○	○
	Adjustable Fitting	○	●	●	○	○
	Capsule Only	○	○	●	○	○
	Sanitary Tri-Clamp	○	○	○	●	●
Thermowell	Barstock	○	○	○	○	○
	Integral Protection Tube	○	●	○	●	●
	Integral Barstock Thermowell	○	○	○	○	○
Stem Designs	Straight	○	●	○	●	●
	Tapered	○	○	○	○	○
	Stepped	○	○	○	○	●
	Straight Tapered Straight	○	○	○	○	○
Thermowell Material	316 Stainless Steel	○	○	○	●	●
	304 Stainless Steel	○	○	○	○	○
	Titanium	○	○	○	○	○
	Carbon Steel	○	○	○	○	○
	Alloy 20	○	○	○	○	○
	Alloy 400	○	○	○	○	○
	Alloy 600	○	○	○	○	○
	304 Stainless Steel with Teflon Coating	○	○	○	○	○
Mounting Configurations	Flange	○	●	○	●	●
	Welded	○	○	○	●	○
	Threaded	○	●	○	●	○
Pipe Clamp Material	304 Stainless Steel	○	○	○	○	○
	Duplex	○	○	○	○	○

KEY: ● Availaible ○ Not available

Sapphire, Multipoint, and Surface Sensor designs are also Available

7.2 – Sensors and Thermowells

Features		0096 	0091 	1097 	0085 
Description		Barstock Thermowell	Barstock Thermowell	Barstock Thermowell for 1067 Sensor	Non-Intrusive Pipe Clamp Sensor
Temperature Range	Temperature Limits				-200 to 300°C (-328 to 572°F)
Thermocouple Type	B	○	○	○	○
	E	○	○	○	○
	J	○	○	○	○
	K	○	○	○	○
	N	○	○	○	○
	R	○	○	○	○
	S	○	○	○	○
	T	○	○	○	○
RTD Elemental Design	Wire Wound	○	○	○	●
	Thin Film	○	○	○	○
Number of Sensor Elements	Single	○	○	○	●
	Dual	○	○	○	●
Accuracy	Class A	○	○	○	●
	Class B	○	○	○	●
	CVD Available	○	○	○	○
	Class 1	○	○	○	○
	Class 2	○	○	○	○
	Special Limits of Error	○	○	○	○
	Standard Limits of Error	○	○	○	○
Sensor Styles	DIN Plate	○	○	○	○
	Spring-loaded Adapter	○	○	○	●
	Welded Adapter	○	○	○	○
	Bayonet	○	○	○	○
	Adjustable Fitting	○	○	○	○
	Capsule Only	○	○	○	○
	Sanitary Tri-Clamp	○	●	○	○
Thermowell	Barstock	●	●	●	○
	Integral Protection Tube	○	○	○	○
	Integral Barstock Thermowell	○	○	○	○
Stem Designs	Straight	●	●	○	○
	Tapered	●	●	○	○
	Stepped	●	●	○	○
	Straight Tapered Straight	○	○	●	○
Thermowell Material	316 Stainless Steel	●	●	●	○
	304 Stainless Steel	●	●	●	○
	Titanium	●	●	●	○
	Carbon Steel	●	●	●	○
	Alloy 20	●	●	●	○
	Alloy 400	●	●	●	○
	Alloy 600	●	●	●	○
	304 Stainless Steel with Teflon Coating	●	●	○	○
Mounting Configurations	Flange	●	●	●	○
	Welded	●	●	●	○
	Threaded	●	●	○	○
Pipe Clamp Material	304 Stainless Steel	○	○	○	●
	Duplex	○	○	○	●

KEY: ● Availaible ○ Not available

Sapphire, Multipoint, and Surface Sensor designs are also Available

8

Reference Materials

TOPIC PAGE

8.1 – Tables

Thermocouples

To calculate the mV value to be applied during a calibration, use the values in these T/C thermoelectric voltage tables. Note these values in these tables have compensated values based on the CJC at the ambient temperature of 0 °C (32 °F). In a application where the ambient temperature is not at 0 °C (32 °F), follow the example below for calculating the mV value for the calibration.

What is the mV value for a Type K T/C at 400 °C (752 °F) at an ambient temperature of 20 °C (68 °F)?

Type K chart mV value at 400 °C (752 °F): 16.395 mV

mV value at the ambient 20 °C (68 °F): 0.798mV

16.395mV – 0.798mV = 15.597mV

Apply 15.597mV with the mV source to achieve the 400 °C (752 °F) input in the transmitter or other device that supports CJC.

T/C Type B - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.1 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	-0.000	-0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	0
10	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003	10
20	-0.003	-0.003	-0.003	-0.003	-0.003	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	20
30	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001	-0.000	30
40	-0.000	-0.000	-0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	40
50	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.006	0.006	50
60	0.006	0.007	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.011	0.011	60
70	0.011	0.012	0.012	0.013	0.014	0.014	0.015	0.015	0.016	0.017	0.017	70
80	0.017	0.018	0.019	0.020	0.020	0.021	0.022	0.022	0.023	0.024	0.025	80
90	0.025	0.026	0.026	0.027	0.028	0.029	0.030	0.031	0.031	0.032	0.033	90
100	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.040	0.041	0.042	0.043	100
110	0.043	0.044	0.045	0.046	0.047	0.048	0.049	0.050	0.051	0.052	0.053	110
120	0.053	0.055	0.056	0.057	0.058	0.059	0.060	0.062	0.063	0.064	0.065	120
130	0.065	0.066	0.068	0.069	0.070	0.071	0.073	0.074	0.075	0.077	0.078	130
140	0.078	0.079	0.081	0.082	0.083	0.085	0.086	0.088	0.089	0.091	0.092	140
150	0.092	0.093	0.095	0.096	0.098	0.099	0.101	0.102	0.104	0.106	0.107	150
160	0.107	0.109	0.110	0.112	0.113	0.115	0.117	0.118	0.120	0.122	0.123	160
170	0.123	0.125	0.127	0.128	0.130	0.132	0.133	0.135	0.137	0.139	0.140	170
180	0.140	0.142	0.144	0.146	0.148	0.149	0.151	0.153	0.155	0.157	0.159	180
190	0.159	0.161	0.163	0.164	0.166	0.168	0.170	0.172	0.174	0.176	0.178	190
200	0.178	0.180	0.182	0.184	0.186	0.188	0.190	0.192	0.194	0.197	0.199	200
210	0.199	0.201	0.203	0.205	0.207	0.209	0.211	0.214	0.216	0.218	0.220	210
220	0.220	0.222	0.225	0.227	0.229	0.231	0.234	0.236	0.238	0.240	0.243	220
230	0.243	0.245	0.247	0.250	0.252	0.254	0.257	0.259	0.262	0.264	0.266	230
240	0.266	0.269	0.271	0.274	0.276	0.279	0.281	0.284	0.286	0.289	0.291	240
250	0.291	0.294	0.296	0.299	0.301	0.304	0.307	0.309	0.312	0.314	0.317	250

Table 8.1.1 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
260	0.317	0.320	0.322	0.325	0.328	0.330	0.333	0.336	0.338	0.341	0.344	260
270	0.344	0.347	0.349	0.352	0.355	0.358	0.360	0.363	0.366	0.369	0.372	270
280	0.372	0.375	0.377	0.380	0.383	0.386	0.389	0.392	0.395	0.398	0.401	280
290	0.401	0.404	0.406	0.409	0.412	0.415	0.418	0.421	0.424	0.427	0.431	290
300	0.431	0.434	0.437	0.440	0.443	0.446	0.449	0.452	0.455	0.458	0.462	300
310	0.462	0.465	0.468	0.471	0.474	0.477	0.481	0.484	0.487	0.490	0.494	310
320	0.494	0.497	0.500	0.503	0.507	0.510	0.513	0.517	0.520	0.523	0.527	320
330	0.527	0.530	0.533	0.537	0.540	0.544	0.547	0.550	0.554	0.557	0.561	330
340	0.561	0.564	0.568	0.571	0.575	0.578	0.582	0.585	0.589	0.592	0.596	340
350	0.596	0.599	0.603	0.606	0.610	0.614	0.617	0.621	0.625	0.628	0.632	350
360	0.632	0.636	0.639	0.643	0.647	0.650	0.654	0.658	0.661	0.665	0.669	360
370	0.669	0.673	0.677	0.680	0.684	0.688	0.692	0.696	0.699	0.703	0.707	370
380	0.707	0.711	0.715	0.719	0.723	0.727	0.730	0.734	0.738	0.742	0.746	380
390	0.746	0.750	0.754	0.758	0.762	0.766	0.770	0.774	0.778	0.782	0.786	390
400	0.786	0.790	0.794	0.799	0.803	0.807	0.811	0.815	0.819	0.823	0.827	400
410	0.827	0.832	0.836	0.840	0.844	0.848	0.853	0.857	0.861	0.865	0.870	410
420	0.870	0.874	0.878	0.882	0.887	0.891	0.895	0.900	0.904	0.908	0.913	420
430	0.913	0.917	0.921	0.926	0.930	0.935	0.939	0.943	0.948	0.952	0.957	430
440	0.957	0.961	0.966	0.970	0.975	0.979	0.984	0.988	0.993	0.997	1.002	440
450	1.002	1.006	1.011	1.015	1.020	1.025	1.029	1.034	1.039	1.043	1.048	450
460	1.048	1.052	1.057	1.062	1.066	1.071	1.076	1.081	1.085	1.090	1.095	460
470	1.095	1.100	1.104	1.109	1.114	1.119	1.123	1.128	1.133	1.138	1.143	470
480	1.143	1.148	1.152	1.157	1.162	1.167	1.172	1.177	1.182	1.187	1.192	480
490	1.192	1.197	1.202	1.206	1.211	1.216	1.221	1.226	1.231	1.236	1.241	490
500	1.241	1.246	1.252	1.257	1.262	1.267	1.272	1.277	1.282	1.287	1.292	500
510	1.292	1.297	1.303	1.308	1.313	1.318	1.323	1.328	1.334	1.339	1.344	510
520	1.344	1.349	1.354	1.360	1.365	1.370	1.375	1.381	1.386	1.391	1.397	520
530	1.397	1.402	1.407	1.413	1.418	1.423	1.429	1.434	1.439	1.445	1.450	530
540	1.450	1.456	1.461	1.467	1.472	1.477	1.483	1.488	1.494	1.499	1.505	540
550	1.505	1.510	1.516	1.521	1.527	1.532	1.538	1.544	1.549	1.555	1.560	550
560	1.560	1.566	1.571	1.577	1.583	1.588	1.594	1.600	1.605	1.611	1.617	560
570	1.617	1.622	1.628	1.634	1.639	1.645	1.651	1.657	1.662	1.668	1.674	570
580	1.674	1.680	1.685	1.691	1.697	1.703	1.709	1.715	1.720	1.726	1.732	580
590	1.732	1.738	1.744	1.750	1.756	1.762	1.767	1.773	1.779	1.785	1.791	590
600	1.791	1.797	1.803	1.809	1.815	1.821	1.827	1.833	1.839	1.845	1.851	600
610	1.851	1.857	1.863	1.869	1.875	1.882	1.888	1.894	1.900	1.906	1.912	610
620	1.912	1.918	1.924	1.931	1.937	1.943	1.949	1.955	1.961	1.968	1.974	620
630	1.974	1.980	1.986	1.993	1.999	2.005	2.011	2.018	2.024	2.030	2.036	630
640	2.036	2.043	2.049	2.055	2.062	2.068	2.074	2.081	2.087	2.094	2.100	640
650	2.100	2.106	2.113	2.119	2.126	2.132	2.139	2.145	2.151	2.158	2.164	650
660	2.164	2.171	2.177	2.184	2.190	2.197	2.203	2.210	2.216	2.223	2.230	660
670	2.230	2.236	2.243	2.249	2.256	2.263	2.269	2.276	2.282	2.289	2.296	670
680	2.296	2.302	2.309	2.316	2.322	2.329	2.336	2.343	2.349	2.356	2.363	680
690	2.363	2.369	2.376	2.383	2.390	2.396	2.403	2.410	2.417	2.424	2.430	690
700	2.430	2.437	2.444	2.451	2.458	2.465	2.472	2.478	2.485	2.492	2.499	700
710	2.499	2.506	2.513	2.520	2.527	2.534	2.541	2.548	2.555	2.562	2.569	710
720	2.569	2.576	2.583	2.590	2.597	2.604	2.611	2.618	2.625	2.632	2.639	720
730	2.639	2.646	2.653	2.660	2.667	2.674	2.682	2.689	2.696	2.703	2.710	730
740	2.710	2.717	2.724	2.732	2.739	2.746	2.753	2.760	2.768	2.775	2.782	740
750	2.782	2.789	2.797	2.804	2.811	2.818	2.826	2.833	2.840	2.848	2.855	750
760	2.855	2.862	2.869	2.877	2.884	2.892	2.899	2.906	2.914	2.921	2.928	760
770	2.928	2.936	2.943	2.951	2.958	2.966	2.973	2.980	2.988	2.995	3.003	770
780	3.003	3.010	3.018	3.025	3.033	3.040	3.048	3.055	3.063	3.070	3.078	780

Table 8.1.1 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
790	3.078	3.086	3.093	3.101	3.108	3.116	3.124	3.131	3.139	3.146	3.154	790
800	3.154	3.162	3.169	3.177	3.185	3.192	3.200	3.208	3.215	3.223	3.231	800
810	3.231	3.239	3.246	3.254	3.262	3.269	3.277	3.285	3.293	3.301	3.308	810
820	3.308	3.316	3.324	3.332	3.340	3.347	3.355	3.363	3.371	3.379	3.387	820
830	3.387	3.395	3.402	3.410	3.418	3.426	3.434	3.442	3.450	3.458	3.466	830
840	3.466	3.474	3.482	3.490	3.498	3.506	3.514	3.522	3.530	3.538	3.546	840
850	3.546	3.554	3.562	3.570	3.578	3.586	3.594	3.602	3.610	3.618	3.626	850
860	3.626	3.634	3.643	3.651	3.659	3.667	3.675	3.683	3.691	3.700	3.708	860
870	3.708	3.716	3.724	3.732	3.741	3.749	3.757	3.765	3.773	3.782	3.790	870
880	3.790	3.798	3.806	3.815	3.823	3.831	3.840	3.848	3.856	3.865	3.873	880
890	3.873	3.881	3.890	3.898	3.906	3.915	3.923	3.931	3.940	3.948	3.957	890
900	3.957	3.965	3.973	3.982	3.990	3.999	4.007	4.016	4.024	4.032	4.041	900
910	4.041	4.049	4.058	4.066	4.075	4.083	4.092	4.100	4.109	4.117	4.126	910
920	4.126	4.135	4.143	4.152	4.160	4.169	4.177	4.186	4.195	4.203	4.212	920
930	4.212	4.220	4.229	4.238	4.246	4.255	4.264	4.272	4.281	4.290	4.298	930
940	4.298	4.307	4.316	4.325	4.333	4.342	4.351	4.359	4.368	4.377	4.386	940
950	4.386	4.394	4.403	4.412	4.421	4.430	4.438	4.447	4.456	4.465	4.474	950
960	4.474	4.483	4.491	4.500	4.509	4.518	4.527	4.536	4.545	4.553	4.562	960
970	4.562	4.571	4.580	4.589	4.598	4.607	4.616	4.625	4.634	4.643	4.652	970
980	4.652	4.661	4.670	4.679	4.688	4.697	4.706	4.715	4.724	4.733	4.742	980
990	4.742	4.751	4.760	4.769	4.778	4.787	4.796	4.805	4.814	4.824	4.833	990
1000	4.833	4.842	4.851	4.860	4.869	4.878	4.887	4.897	4.906	4.915	4.924	1000
1010	4.924	4.933	4.942	4.952	4.961	4.970	4.979	4.989	4.998	5.007	5.016	1010
1020	5.016	5.025	5.035	5.044	5.053	5.063	5.072	5.081	5.090	5.100	5.109	1020
1030	5.109	5.118	5.128	5.137	5.146	5.156	5.165	5.174	5.184	5.193	5.202	1030
1040	5.202	5.212	5.221	5.231	5.240	5.249	5.259	5.268	5.278	5.287	5.297	1040
1050	5.297	5.306	5.316	5.325	5.334	5.344	5.353	5.363	5.372	5.382	5.391	1050
1060	5.391	5.401	5.410	5.420	5.429	5.439	5.449	5.458	5.468	5.477	5.487	1060
1070	5.487	5.496	5.506	5.516	5.525	5.535	5.544	5.554	5.564	5.573	5.583	1070
1080	5.583	5.593	5.602	5.612	5.621	5.631	5.641	5.651	5.660	5.670	5.680	1080
1090	5.680	5.689	5.699	5.709	5.718	5.728	5.738	5.748	5.757	5.767	5.777	1090
1100	5.777	5.787	5.796	5.806	5.816	5.826	5.836	5.845	5.855	5.865	5.875	1100
1110	5.875	5.885	5.895	5.904	5.914	5.924	5.934	5.944	5.954	5.964	5.973	1110
1120	5.973	5.983	5.993	6.003	6.013	6.023	6.033	6.043	6.053	6.063	6.073	1120
1130	6.073	6.083	6.093	6.102	6.112	6.122	6.132	6.142	6.152	6.162	6.172	1130
1140	6.172	6.182	6.192	6.202	6.212	6.223	6.233	6.243	6.253	6.263	6.273	1140
1150	6.273	6.283	6.293	6.303	6.313	6.323	6.333	6.343	6.353	6.364	6.374	1150
1160	6.374	6.384	6.394	6.404	6.414	6.424	6.435	6.445	6.455	6.465	6.475	1160
1170	6.475	6.485	6.496	6.506	6.516	6.526	6.536	6.547	6.557	6.567	6.577	1170
1180	6.577	6.588	6.598	6.608	6.618	6.629	6.639	6.649	6.659	6.670	6.680	1180
1190	6.680	6.690	6.701	6.711	6.721	6.732	6.742	6.752	6.763	6.773	6.783	1190
1200	6.783	6.794	6.804	6.814	6.825	6.835	6.846	6.856	6.866	6.877	6.887	1200
1210	6.887	6.898	6.908	6.918	6.929	6.939	6.950	6.960	6.971	6.981	6.991	1210
1220	6.991	7.002	7.012	7.023	7.033	7.044	7.054	7.065	7.075	7.086	7.096	1220
1230	7.096	7.107	7.117	7.128	7.138	7.149	7.159	7.170	7.181	7.191	7.202	1230
1240	7.202	7.212	7.223	7.233	7.244	7.255	7.265	7.276	7.286	7.297	7.308	1240
1250	7.308	7.318	7.329	7.339	7.350	7.361	7.371	7.382	7.393	7.403	7.414	1250
1260	7.414	7.425	7.435	7.446	7.457	7.467	7.478	7.489	7.500	7.510	7.521	1260
1270	7.521	7.532	7.542	7.553	7.564	7.575	7.585	7.596	7.607	7.618	7.628	1270
1280	7.628	7.639	7.650	7.661	7.671	7.682	7.693	7.704	7.715	7.725	7.736	1280
1290	7.736	7.747	7.758	7.769	7.780	7.790	7.801	7.812	7.823	7.834	7.845	1290
1300	7.845	7.855	7.866	7.877	7.888	7.899	7.910	7.921	7.932	7.943	7.953	1300
1310	7.953	7.964	7.975	7.986	7.997	8.008	8.019	8.030	8.041	8.052	8.063	1310

Table 8.1.1 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1320	8.063	8.074	8.085	8.096	8.107	8.118	8.128	8.139	8.150	8.161	8.172	1320
1330	8.172	8.183	8.194	8.205	8.216	8.227	8.238	8.249	8.261	8.272	8.283	1330
1340	8.283	8.294	8.305	8.316	8.327	8.338	8.349	8.360	8.371	8.382	8.393	1340
1350	8.393	8.404	8.415	8.426	8.437	8.449	8.460	8.471	8.482	8.493	8.504	1350
1360	8.504	8.515	8.526	8.538	8.549	8.560	8.571	8.582	8.593	8.604	8.616	1360
1370	8.616	8.627	8.638	8.649	8.660	8.671	8.683	8.694	8.705	8.716	8.727	1370
1380	8.727	8.738	8.750	8.761	8.772	8.783	8.795	8.806	8.817	8.828	8.839	1380
1390	8.839	8.851	8.862	8.873	8.884	8.896	8.907	8.918	8.929	8.941	8.952	1390
1400	8.952	8.963	8.974	8.986	8.997	9.008	9.020	9.031	9.042	9.053	9.065	1400
1410	9.065	9.076	9.087	9.099	9.110	9.121	9.133	9.144	9.155	9.167	9.178	1410
1420	9.178	9.189	9.201	9.212	9.223	9.235	9.246	9.257	9.269	9.280	9.291	1420
1430	9.291	9.303	9.314	9.326	9.337	9.348	9.360	9.371	9.382	9.394	9.405	1430
1440	9.405	9.417	9.428	9.439	9.451	9.462	9.474	9.485	9.497	9.508	9.519	1440
1450	9.519	9.531	9.542	9.554	9.565	9.577	9.588	9.599	9.611	9.622	9.634	1450
1460	9.634	9.645	9.657	9.668	9.680	9.691	9.703	9.714	9.726	9.737	9.748	1460
1470	9.748	9.760	9.771	9.783	9.794	9.806	9.817	9.829	9.840	9.852	9.863	1470
1480	9.863	9.875	9.886	9.898	9.909	9.921	9.933	9.944	9.956	9.967	9.979	1480
1490	9.979	9.990	10.002	10.013	10.025	10.036	10.048	10.059	10.071	10.082	10.094	1490
1500	10.094	10.106	10.117	10.129	10.140	10.152	10.163	10.175	10.187	10.198	10.210	1500
1510	10.210	10.221	10.233	10.244	10.256	10.268	10.279	10.291	10.302	10.314	10.325	1510
1520	10.325	10.337	10.349	10.360	10.372	10.383	10.395	10.407	10.418	10.430	10.441	1520
1530	10.441	10.453	10.465	10.476	10.488	10.500	10.511	10.523	10.534	10.546	10.558	1530
1540	10.558	10.569	10.581	10.593	10.604	10.616	10.627	10.639	10.651	10.662	10.674	1540
1550	10.674	10.686	10.697	10.709	10.721	10.732	10.744	10.756	10.767	10.779	10.790	1550
1560	10.790	10.802	10.814	10.825	10.837	10.849	10.860	10.872	10.884	10.895	10.907	1560
1570	10.907	10.919	10.930	10.942	10.954	10.965	10.977	10.989	11.000	11.012	11.024	1570
1580	11.024	11.035	11.047	11.059	11.070	11.082	11.094	11.105	11.117	11.129	11.141	1580
1590	11.141	11.152	11.164	11.176	11.187	11.199	11.211	11.222	11.234	11.246	11.257	1590
1600	11.257	11.269	11.281	11.292	11.304	11.316	11.328	11.339	11.351	11.363	11.374	1600
1610	11.374	11.386	11.398	11.409	11.421	11.433	11.444	11.456	11.468	11.480	11.491	1610
1620	11.491	11.503	11.515	11.526	11.538	11.550	11.561	11.573	11.585	11.597	11.608	1620
1630	11.608	11.620	11.632	11.643	11.655	11.667	11.678	11.690	11.702	11.714	11.725	1630
1640	11.725	11.737	11.749	11.760	11.772	11.784	11.795	11.807	11.819	11.830	11.842	1640
1650	11.842	11.854	11.866	11.877	11.889	11.901	11.912	11.924	11.936	11.947	11.959	1650
1660	11.959	11.971	11.983	11.994	12.006	12.018	12.029	12.041	12.053	12.064	12.076	1660
1670	12.076	12.088	12.099	12.111	12.123	12.134	12.146	12.158	12.170	12.181	12.193	1670
1680	12.193	12.205	12.216	12.228	12.240	12.251	12.263	12.275	12.286	12.298	12.310	1680
1690	12.310	12.321	12.333	12.345	12.356	12.368	12.380	12.391	12.403	12.415	12.426	1690
1700	12.426	12.438	12.450	12.461	12.473	12.485	12.496	12.508	12.520	12.531	12.543	1700
1710	12.543	12.555	12.566	12.578	12.590	12.601	12.613	12.624	12.636	12.648	12.659	1710
1720	12.659	12.671	12.683	12.694	12.706	12.718	12.729	12.741	12.752	12.764	12.776	1720
1730	12.776	12.787	12.799	12.811	12.822	12.834	12.845	12.857	12.869	12.880	12.892	1730
1740	12.892	12.903	12.915	12.927	12.938	12.950	12.961	12.973	12.985	12.996	13.008	1740
1750	13.008	13.019	13.031	13.043	13.054	13.066	13.077	13.089	13.100	13.112	13.124	1750
1760	13.124	13.135	13.147	13.158	13.170	13.181	13.193	13.204	13.216	13.228	13.239	1760
1770	13.239	13.251	13.262	13.274	13.285	13.297	13.308	13.320	13.331	13.343	13.354	1770
1780	13.354	13.366	13.378	13.389	13.401	13.412	13.424	13.435	13.447	13.458	13.470	1780
1790	13.470	13.481	13.493	13.504	13.516	13.527	13.539	13.550	13.562	13.573	13.585	1790
1800	13.585	13.596	13.607	13.619	13.630	13.642	13.653	13.665	13.676	13.688	13.699	1800
1810	13.699	13.711	13.722	13.733	13.745	13.756	13.768	13.779	13.791	13.802	13.814	1810

T/C Type B - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.2 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
30			-0.000	-0.000	-0.000	-0.000	-0.001	-0.001	-0.001	-0.001	-0.001	30
40	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	40
50	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	50
60	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	60
70	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.002	-0.002	-0.002	-0.002	70
80	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	80
90	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	90
100	-0.001	-0.001	-0.001	-0.001	-0.000	-0.000	-0.000	-0.000	0.000	0.000	0.000	100
110	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	110
120	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.004	0.004	120
130	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.006	130
140	0.006	0.006	0.007	0.007	0.007	0.007	0.008	0.008	0.008	0.009	0.009	140
150	0.009	0.009	0.009	0.010	0.010	0.010	0.011	0.011	0.011	0.012	0.012	150
160	0.012	0.012	0.013	0.013	0.013	0.014	0.014	0.014	0.015	0.015	0.015	160
170	0.015	0.016	0.016	0.016	0.017	0.017	0.017	0.018	0.018	0.019	0.019	170
180	0.019	0.019	0.020	0.020	0.021	0.021	0.021	0.022	0.022	0.023	0.023	180
190	0.023	0.023	0.024	0.024	0.025	0.025	0.026	0.026	0.027	0.027	0.027	190
200	0.027	0.028	0.028	0.029	0.029	0.030	0.030	0.031	0.031	0.032	0.032	200
210	0.032	0.033	0.033	0.034	0.034	0.035	0.035	0.036	0.036	0.037	0.037	210
220	0.037	0.038	0.038	0.039	0.039	0.040	0.041	0.041	0.042	0.042	0.043	220
230	0.043	0.043	0.044	0.044	0.045	0.046	0.046	0.047	0.047	0.048	0.049	230
240	0.049	0.049	0.050	0.050	0.051	0.052	0.052	0.053	0.053	0.054	0.055	240
250	0.055	0.055	0.056	0.057	0.057	0.058	0.058	0.059	0.060	0.060	0.061	250
260	0.061	0.062	0.062	0.063	0.064	0.064	0.065	0.066	0.067	0.067	0.068	260
270	0.068	0.069	0.069	0.070	0.071	0.071	0.072	0.073	0.074	0.074	0.075	270
280	0.075	0.076	0.077	0.077	0.078	0.079	0.080	0.080	0.081	0.082	0.083	280
290	0.083	0.083	0.084	0.085	0.086	0.086	0.087	0.088	0.089	0.090	0.090	290
300	0.090	0.091	0.092	0.093	0.094	0.094	0.095	0.096	0.097	0.098	0.099	300
310	0.099	0.099	0.100	0.101	0.102	0.103	0.104	0.104	0.105	0.106	0.107	310
320	0.107	0.108	0.109	0.110	0.111	0.111	0.112	0.113	0.114	0.115	0.116	320
330	0.116	0.117	0.118	0.119	0.120	0.120	0.121	0.122	0.123	0.124	0.125	330
340	0.125	0.126	0.127	0.128	0.129	0.130	0.131	0.132	0.133	0.134	0.135	340
350	0.135	0.136	0.137	0.138	0.138	0.139	0.140	0.141	0.142	0.143	0.144	350
360	0.144	0.145	0.146	0.147	0.148	0.149	0.151	0.152	0.153	0.154	0.155	360
370	0.155	0.156	0.157	0.158	0.159	0.160	0.161	0.162	0.163	0.164	0.165	370
380	0.165	0.166	0.167	0.168	0.169	0.171	0.172	0.173	0.174	0.175	0.176	380
390	0.176	0.177	0.178	0.179	0.180	0.182	0.183	0.184	0.185	0.186	0.187	390
400	0.187	0.188	0.189	0.191	0.192	0.193	0.194	0.195	0.196	0.197	0.199	400
410	0.199	0.200	0.201	0.202	0.203	0.205	0.206	0.207	0.208	0.209	0.210	410
420	0.210	0.212	0.213	0.214	0.215	0.217	0.218	0.219	0.220	0.221	0.223	420
430	0.223	0.224	0.225	0.226	0.228	0.229	0.230	0.231	0.233	0.234	0.235	430
440	0.235	0.236	0.238	0.239	0.240	0.242	0.243	0.244	0.245	0.247	0.248	440
450	0.248	0.249	0.251	0.252	0.253	0.254	0.256	0.257	0.258	0.260	0.261	450
460	0.261	0.262	0.264	0.265	0.266	0.268	0.269	0.271	0.272	0.273	0.275	460
470	0.275	0.276	0.277	0.279	0.280	0.281	0.283	0.284	0.286	0.287	0.288	470
480	0.288	0.290	0.291	0.293	0.294	0.295	0.297	0.298	0.300	0.301	0.303	480
490	0.303	0.304	0.305	0.307	0.308	0.310	0.311	0.313	0.314	0.315	0.317	490

Table 8.1.2 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
500	0.317	0.318	0.320	0.321	0.323	0.324	0.326	0.327	0.329	0.330	0.332	500
510	0.332	0.333	0.335	0.336	0.338	0.339	0.341	0.342	0.344	0.345	0.347	510
520	0.347	0.348	0.350	0.351	0.353	0.355	0.356	0.358	0.359	0.361	0.362	520
530	0.362	0.364	0.365	0.367	0.369	0.370	0.372	0.373	0.375	0.376	0.378	530
540	0.378	0.380	0.381	0.383	0.384	0.386	0.388	0.389	0.391	0.392	0.394	540
550	0.394	0.396	0.397	0.399	0.401	0.402	0.404	0.405	0.407	0.409	0.410	550
560	0.410	0.412	0.414	0.415	0.417	0.419	0.420	0.422	0.424	0.425	0.427	560
570	0.427	0.429	0.431	0.432	0.434	0.436	0.437	0.439	0.441	0.442	0.444	570
580	0.444	0.446	0.448	0.449	0.451	0.453	0.455	0.456	0.458	0.460	0.462	580
590	0.462	0.463	0.465	0.467	0.469	0.470	0.472	0.474	0.476	0.477	0.479	590
600	0.479	0.481	0.483	0.485	0.486	0.488	0.490	0.492	0.494	0.495	0.497	600
610	0.497	0.499	0.501	0.503	0.504	0.506	0.508	0.510	0.512	0.514	0.515	610
620	0.515	0.517	0.519	0.521	0.523	0.525	0.527	0.528	0.530	0.532	0.534	620
630	0.534	0.536	0.538	0.540	0.542	0.544	0.545	0.547	0.549	0.551	0.553	630
640	0.553	0.555	0.557	0.559	0.561	0.563	0.565	0.566	0.568	0.570	0.572	640
650	0.572	0.574	0.576	0.578	0.580	0.582	0.584	0.586	0.588	0.590	0.592	650
660	0.592	0.594	0.596	0.598	0.600	0.602	0.604	0.606	0.608	0.610	0.612	660
670	0.612	0.614	0.616	0.618	0.620	0.622	0.624	0.626	0.628	0.630	0.632	670
680	0.632	0.634	0.636	0.638	0.640	0.642	0.644	0.646	0.648	0.650	0.652	680
690	0.652	0.654	0.656	0.659	0.661	0.663	0.665	0.667	0.669	0.671	0.673	690
700	0.673	0.675	0.677	0.679	0.682	0.684	0.686	0.688	0.690	0.692	0.694	700
710	0.694	0.696	0.699	0.701	0.703	0.705	0.707	0.709	0.711	0.714	0.716	710
720	0.716	0.718	0.720	0.722	0.724	0.727	0.729	0.731	0.733	0.735	0.737	720
730	0.737	0.740	0.742	0.744	0.746	0.748	0.751	0.753	0.755	0.757	0.759	730
740	0.759	0.762	0.764	0.766	0.768	0.771	0.773	0.775	0.777	0.780	0.782	740
750	0.782	0.784	0.786	0.789	0.791	0.793	0.795	0.798	0.800	0.802	0.804	750
760	0.804	0.807	0.809	0.811	0.814	0.816	0.818	0.821	0.823	0.825	0.827	760
770	0.827	0.830	0.832	0.834	0.837	0.839	0.841	0.844	0.846	0.848	0.851	770
780	0.851	0.853	0.855	0.858	0.860	0.862	0.865	0.867	0.870	0.872	0.874	780
790	0.874	0.877	0.879	0.881	0.884	0.886	0.889	0.891	0.893	0.896	0.898	790
800	0.898	0.901	0.903	0.905	0.908	0.910	0.913	0.915	0.918	0.920	0.922	800
810	0.922	0.925	0.927	0.930	0.932	0.935	0.937	0.939	0.942	0.944	0.947	810
820	0.947	0.949	0.952	0.954	0.957	0.959	0.962	0.964	0.967	0.969	0.972	820
830	0.972	0.974	0.977	0.979	0.982	0.984	0.987	0.989	0.992	0.994	0.997	830
840	0.997	0.999	1.002	1.004	1.007	1.009	1.012	1.014	1.017	1.020	1.022	840
850	1.022	1.025	1.027	1.030	1.032	1.035	1.037	1.040	1.043	1.045	1.048	850
860	1.048	1.050	1.053	1.056	1.058	1.061	1.063	1.066	1.069	1.071	1.074	860
870	1.074	1.076	1.079	1.082	1.084	1.087	1.090	1.092	1.095	1.097	1.100	870
880	1.100	1.103	1.105	1.108	1.111	1.113	1.116	1.119	1.121	1.124	1.127	880
890	1.127	1.129	1.132	1.135	1.137	1.140	1.143	1.145	1.148	1.151	1.153	890
900	1.153	1.156	1.159	1.162	1.164	1.167	1.170	1.172	1.175	1.178	1.181	900
910	1.181	1.183	1.186	1.189	1.192	1.194	1.197	1.200	1.203	1.205	1.208	910
920	1.208	1.211	1.214	1.216	1.219	1.222	1.225	1.228	1.230	1.233	1.236	920
930	1.236	1.239	1.241	1.244	1.247	1.250	1.253	1.255	1.258	1.261	1.264	930
940	1.264	1.267	1.270	1.272	1.275	1.278	1.281	1.284	1.287	1.289	1.292	940
950	1.292	1.295	1.298	1.301	1.304	1.307	1.309	1.312	1.315	1.318	1.321	950
960	1.321	1.324	1.327	1.330	1.332	1.335	1.338	1.341	1.344	1.347	1.350	960
970	1.350	1.353	1.356	1.359	1.361	1.364	1.367	1.370	1.373	1.376	1.379	970
980	1.379	1.382	1.385	1.388	1.391	1.394	1.397	1.400	1.403	1.406	1.409	980
990	1.409	1.411	1.414	1.417	1.420	1.423	1.426	1.429	1.432	1.435	1.438	990
1000	1.438	1.441	1.444	1.447	1.450	1.453	1.456	1.459	1.462	1.465	1.468	1000
1010	1.468	1.471	1.474	1.477	1.480	1.483	1.487	1.490	1.493	1.496	1.499	1010
1020	1.499	1.502	1.505	1.508	1.511	1.514	1.517	1.520	1.523	1.526	1.529	1020

Table 8.1.2 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1030	1.529	1.532	1.536	1.539	1.542	1.545	1.548	1.551	1.554	1.557	1.560	1030
1040	1.560	1.563	1.566	1.570	1.573	1.576	1.579	1.582	1.585	1.588	1.591	1040
1050	1.591	1.595	1.598	1.601	1.604	1.607	1.610	1.613	1.617	1.620	1.623	1050
1060	1.623	1.262	1.629	1.632	1.636	1.639	1.642	1.645	1.648	1.652	1.655	1060
1070	1.655	1.658	1.661	1.664	1.668	1.671	1.674	1.677	1.680	1.684	1.687	1070
1080	1.687	1.690	1.693	1.696	1.700	1.703	1.706	1.709	1.713	1.716	1.719	1080
1090	1.719	1.722	1.726	1.729	1.732	1.735	1.739	1.742	1.745	1.748	1.752	1090
1100	1.752	1.755	1.758	1.762	1.765	1.768	1.771	1.775	1.778	1.781	1.785	1100
1110	1.785	1.788	1.791	1.795	1.798	1.801	1.804	1.808	1.811	1.814	1.818	1110
1120	1.818	1.821	1.824	1.828	1.831	1.834	1.838	1.841	1.844	1.848	1.851	1120
1130	1.851	1.855	1.858	1.861	1.865	1.868	1.871	1.875	1.878	1.882	1.885	1130
1140	1.885	1.888	1.892	1.895	1.898	1.902	1.905	1.909	1.912	1.915	1.919	1140
1150	1.919	1.922	1.926	1.929	1.933	1.936	1.939	1.943	1.946	1.950	1.953	1150
1160	1.953	1.957	1.960	1.963	1.967	1.970	1.974	1.977	1.981	1.984	1.988	1160
1170	1.988	1.991	1.995	1.998	2.002	2.005	2.009	2.012	2.015	2.019	2.022	1170
1180	2.022	2.026	2.029	2.033	2.036	2.040	2.043	2.047	2.051	2.054	2.058	1180
1190	2.058	2.061	2.065	2.068	2.072	2.075	2.079	2.082	2.086	2.089	2.093	1190
1200	2.093	2.096	2.100	2.104	2.107	2.111	2.114	2.118	2.121	2.125	2.128	1200
1210	2.128	2.132	2.136	2.139	2.143	2.146	2.150	2.154	2.157	2.161	2.164	1210
1220	2.164	2.168	2.172	2.175	2.179	2.182	2.186	2.190	2.193	2.197	2.201	1220
1230	2.201	2.204	2.208	2.211	2.215	2.219	2.222	2.226	2.230	2.233	2.237	1230
1240	2.237	2.241	2.244	2.248	2.252	2.255	2.259	2.263	2.266	2.270	2.274	1240
1250	2.274	2.277	2.281	2.285	2.288	2.292	2.296	2.299	2.303	2.307	2.311	1250
1260	2.311	2.314	2.318	2.322	2.325	2.329	2.333	2.337	2.340	2.344	2.348	1260
1270	2.348	2.351	2.355	2.359	2.363	2.366	2.70	2.374	2.378	2.381	2.385	1270
1280	2.385	2.389	2.393	2.396	2.400	2.404	2.408	2.412	2.415	2.419	2.423	1280
1290	2.423	2.427	2.430	2.434	2.438	2.442	2.446	2.449	2.453	2.457	2.461	1290
1300	2.461	2.465	2.469	2.472	2.476	2.480	2.484	2.488	2.491	2.495	2.499	1300
1310	2.499	2.503	2.507	2.511	2.515	2.518	2.522	2.526	2.30	2.534	2.538	1310
1320	2.538	2.542	2.545	2.549	2.553	2.557	2.561	2.565	2.569	2.573	2.576	1320
1340	2.576	2.580	2.584	2.588	2.592	2.596	2.600	2.604	2.608	2.612	2.615	1340
1350	2.615	2.619	2.623	2.627	2.631	2.635	2.639	2.643	2.647	2.651	2.655	1350
1360	2.655	2.659	2.663	2.667	2.670	2.674	2.678	2.682	2.686	2.690	2.694	1360
1370	2.694	2.698	2.702	2.706	2.710	2.714	2.718	2.722	2.726	2.730	2.734	1370
1380	2.734	2.738	2.742	2.746	2.750	2.754	2.758	2.762	2.766	2.770	2.774	1380
1390	2.774	2.778	2.782	2.786	2.790	2.794	2.798	2.802	2.806	2.810	2.814	1390
1400	2.814	2.818	2.822	2.826	2.830	2.835	2.839	2.843	2.847	2.851	2.855	1400
1410	2.855	2.859	2.863	2.867	2.871	2.875	2.879	2.883	2.887	2.892	2.896	1410
1420	2.896	2.900	2.904	2.908	2.912	2.916	2.920	2.924	2.928	2.933	2.937	1420
1430	2.937	2.941	2.945	2.949	2.953	2.957	2.961	2.966	2.970	2.974	2.978	1430
1450	2.978	2.982	2.986	2.990	2.995	2.999	3.003	3.007	3.011	3.015	3.019	1450
1460	3.019	3.024	3.028	3.032	3.036	3.040	3.045	3.049	3.053	3.057	3.061	1460
1470	3.061	3.065	3.070	3.074	3.078	3.082	3.086	3.091	3.095	3.099	3.103	1470
1480	3.103	3.107	3.112	3.116	3.120	3.124	3.129	3.133	3.137	3.141	3.146	1480
1490	3.231	3.235	3.239	3.244	3.248	3.252	3.257	3.261	3.265	3.269	3.274	1490
1500	3.274	3.278	3.282	3.287	3.291	3.295	3.300	3.304	3.308	3.313	3.317	1500
1510	3.317	3.321	3.326	3.330	3.334	3.339	3.343	3.347	3.352	3.356	3.361	1510
1520	3.361	3.365	3.369	3.374	3.378	3.382	3.387	3.391	3.395	3.400	3.404	1520
1530	3.404	3.409	3.413	3.417	3.422	3.426	3.431	3.435	3.439	3.444	3.448	1530
1540	3.448	3.453	3.457	3.461	3.466	3.470	3.475	3.479	3.484	3.488	3.492	1540
1550	3.492	3.497	3.501	3.506	3.510	3.515	3.519	3.523	3.528	3.532	3.537	1550
1560	3.537	3.541	3.546	3.550	3.555	3.559	3.564	3.568	3.573	3.577	3.581	1560
1570	3.581	3.586	3.590	3.595	3.599	3.604	3.608	3.613	3.617	3.622	3.626	1570

Table 8.1.2 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1580	3.626	3.631	3.635	3.640	3.644	3.649	3.653	3.658	3.662	3.667	3.672	1580
1590	3.672	3.676	3.681	3.685	3.690	3.694	3.699	3.703	3.708	3.712	3.717	1590
1600	3.717	3.721	3.726	3.731	3.735	3.740	3.744	3.749	3.753	3.758	3.762	1600
1610	3.762	3.767	3.772	3.776	3.781	3.785	3.790	3.795	3.799	3.804	3.808	1610
1620	3.808	3.813	3.818	3.822	3.827	3.831	3.836	3.841	3.845	3.850	3.854	1620
1630	3.854	3.859	3.864	3.868	3.873	3.877	3.882	3.887	3.891	3.896	3.901	1630
1640	3.901	3.905	3.910	3.915	3.919	3.924	3.929	3.933	3.938	3.943	3.947	1640
1650	3.947	3.952	3.957	3.961	3.966	3.971	3.975	3.980	3.985	3.989	3.994	1650
1660	3.994	3.999	4.003	4.008	4.013	4.017	4.022	4.027	4.031	4.036	4.041	1660
1670	4.041	4.046	4.050	4.055	4.060	4.064	4.069	4.074	4.079	4.083	4.088	1670
1680	4.088	4.093	4.098	4.102	4.107	4.112	4.117	4.121	4.126	4.131	4.136	1680
1690	4.136	4.140	4.145	4.150	4.155	4.159	4.164	4.169	4.174	4.178	4.183	1690
1700	4.183	4.188	4.193	4.198	4.202	4.207	4.212	4.217	4.221	4.226	4.231	1700
1710	4.231	4.236	4.241	4.245	4.250	4.255	4.260	4.265	4.269	4.274	4.279	1710
1720	4.279	4.284	4.289	4.294	4.298	4.303	4.308	4.313	4.318	4.323	4.327	1720
1730	4.327	4.332	4.337	4.342	4.347	4.352	4.357	4.361	4.366	4.371	4.376	1730
1740	4.376	4.381	4.386	4.391	4.395	4.400	4.405	4.410	4.415	4.420	4.425	1740
1750	4.425	4.430	4.435	4.439	4.444	4.449	4.454	4.459	4.464	4.469	4.474	1750
1760	4.474	4.479	4.484	4.488	4.493	4.498	4.503	4.508	4.513	4.518	4.523	1760
1770	4.523	4.528	4.533	4.538	4.543	4.548	4.552	4.557	4.562	4.567	4.572	1770
1780	4.572	4.577	4.582	4.587	4.592	4.597	4.602	4.607	4.612	4.617	4.622	1780
1790	4.622	4.627	4.632	4.637	4.642	4.647	4.652	4.657	4.662	4.667	4.672	1790
1800	4.672	4.677	4.682	4.687	4.692	4.697	4.702	4.707	4.712	4.717	4.722	1800
1810	4.722	4.727	4.732	4.737	4.742	4.747	4.752	4.757	4.762	4.767	4.772	1810
1820	4.772	4.777	4.782	4.787	4.792	4.797	4.802	4.807	4.812	4.817	4.823	1820
1830	4.823	4.828	4.833	4.838	4.843	4.848	4.853	4.858	4.863	4.868	4.873	1830
1840	4.873	4.878	4.883	4.888	4.894	4.899	4.904	4.909	4.914	4.919	4.924	1840
1850	4.924	4.929	4.934	4.939	4.945	4.950	4.955	4.960	4.965	4.970	4.975	1850
1860	4.975	4.980	4.985	4.991	4.996	5.001	5.006	5.011	5.016	5.021	5.027	1860
1870	5.027	5.032	5.037	5.042	5.047	5.052	5.057	5.063	5.068	5.073	5.078	1870
1880	5.078	5.083	5.088	5.094	5.099	5.104	5.109	5.114	5.119	5.125	5.130	1880
1890	5.130	5.135	5.140	5.145	5.150	5.156	5.161	5.166	5.171	5.176	5.182	1890
1900	5.182	5.187	5.192	5.197	5.202	5.208	5.213	5.218	5.223	5.229	5.234	1900
1910	5.234	5.239	5.244	5.249	5.255	5.260	5.265	5.270	5.276	5.281	5.286	1910
1920	5.286	5.291	5.297	5.302	5.307	5.312	5.318	5.323	5.328	5.333	5.339	1920
1930	5.339	5.344	5.349	5.354	5.360	5.365	5.370	5.376	5.381	5.386	5.391	1930
1940	5.391	5.397	5.402	5.407	5.413	5.418	5.423	5.428	5.434	5.439	5.444	1940
1950	5.444	5.450	5.455	5.460	5.466	5.471	5.476	5.482	5.487	5.492	5.497	1950
1960	5.497	5.503	5.508	5.513	5.519	5.524	5.529	5.535	5.540	5.545	5.551	1960
1970	5.551	5.556	5.561	5.567	5.572	5.578	5.583	5.588	5.594	5.599	5.604	1970
1980	5.604	5.610	5.615	5.620	5.626	5.631	5.637	5.642	5.647	5.653	5.658	1980
1990	5.658	5.663	5.669	5.674	5.680	5.685	5.690	5.696	5.701	5.707	5.712	1990
2000	5.712	5.717	5.723	5.728	5.734	5.739	5.744	5.750	5.755	5.761	5.766	2000
2010	5.766	5.771	5.777	5.782	5.788	5.793	5.799	5.804	5.810	5.815	5.820	2010
2020	5.820	5.826	5.831	5.837	5.842	5.848	5.853	5.859	5.864	5.869	5.875	2020
2030	5.875	5.880	5.886	5.891	5.897	5.902	5.908	5.913	5.919	5.924	5.930	2030
2040	5.930	5.935	5.941	5.946	5.951	5.957	5.962	5.968	5.973	5.979	5.984	2040
2050	5.984	5.990	5.995	6.001	6.006	6.012	6.017	6.023	6.028	6.034	6.039	2050
2060	6.039	6.045	6.051	6.056	6.062	6.067	6.073	6.078	6.084	6.089	6.095	2060
2070	6.095	6.100	6.106	6.111	6.117	6.122	6.128	6.134	6.139	6.145	6.150	2070
2080	6.150	6.156	6.161	6.167	6.172	6.178	6.184	6.189	6.195	6.200	6.206	2080
2090	6.206	6.211	6.217	6.223	6.228	6.234	6.239	6.245	6.250	6.256	6.262	2090
2100	6.262	6.267	6.273	6.278	6.284	6.290	6.295	6.301	6.306	6.312	6.318	2100

Table 8.1.2 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2110	6.318	6.323	6.329	6.334	6.340	6.346	6.351	6.357	6.362	6.368	6.374	2110
2120	6.374	6.379	6.385	6.391	6.396	6.402	6.408	6.413	6.419	6.424	6.430	2120
2130	6.430	6.436	6.441	6.447	6.453	6.458	6.464	6.470	6.475	6.481	6.487	2130
2140	6.487	6.492	6.498	6.504	6.509	6.515	6.521	6.526	6.532	6.538	6.543	2140
2150	6.543	6.549	6.555	6.560	6.566	6.572	6.577	6.583	6.589	6.594	6.600	2150
2160	6.600	6.606	6.612	6.617	6.623	6.629	6.634	6.640	6.646	6.651	6.657	2160
2170	6.657	6.663	6.669	6.674	6.680	6.686	6.692	6.697	6.703	6.709	6.714	2170
2180	6.714	6.720	6.726	6.732	6.737	6.743	6.749	6.755	6.760	6.766	6.772	2180
2190	6.772	6.778	6.783	6.789	6.795	6.801	6.806	6.812	6.818	6.824	6.829	2190
2200	6.829	6.835	6.841	6.847	6.852	6.858	6.864	6.870	6.876	6.881	6.887	2200
2210	6.887	6.893	6.899	6.904	6.910	6.916	6.922	6.928	6.933	6.939	6.945	2210
2220	6.945	6.951	6.957	6.962	6.968	6.974	6.980	6.986	6.991	6.997	7.003	2220
2230	7.003	7.009	7.015	7.021	7.026	7.032	7.038	7.044	7.050	7.055	7.061	2230
2240	7.061	7.067	7.073	7.079	7.085	7.090	7.096	7.102	7.108	7.114	7.120	2240
2250	7.120	7.126	7.131	7.137	7.143	7.149	7.155	7.161	7.167	7.172	7.178	2250
2260	7.178	7.184	7.190	7.196	7.202	7.208	7.213	7.219	7.225	7.231	7.237	2260
2270	7.237	7.243	7.249	7.255	7.260	7.266	7.272	7.278	7.284	7.290	7.296	2270
2280	7.296	7.302	7.308	7.314	7.319	7.325	7.331	7.337	7.343	7.349	7.355	2280
2290	7.355	7.361	7.367	7.373	7.378	7.384	7.390	7.396	7.402	7.408	7.414	2290
2300	7.414	7.420	7.426	7.432	7.438	7.444	7.450	7.456	7.461	7.467	7.473	2300
2310	7.473	7.479	7.485	7.491	7.497	7.503	7.509	7.515	7.521	7.527	7.533	2310
2320	7.533	7.539	7.545	7.551	7.557	7.563	7.569	7.575	7.581	7.587	7.592	2320
2330	7.592	7.598	7.604	7.610	7.616	7.622	7.628	7.634	7.640	7.646	7.652	2330
2340	7.652	7.658	7.664	7.670	7.676	7.682	7.688	7.694	7.700	7.706	7.712	2340
2350	7.712	7.718	7.724	7.730	7.736	7.742	7.748	7.754	7.760	7.766	7.772	2350
2360	7.772	7.778	7.784	7.790	7.796	7.802	7.808	7.814	7.820	7.827	7.833	2360
2370	7.833	7.839	7.845	7.851	7.857	7.863	7.869	7.875	7.881	7.887	7.893	2370
2380	7.893	7.899	7.905	7.911	7.917	7.923	7.929	7.935	7.941	7.947	7.953	2380
2390	7.953	7.959	7.966	7.972	7.978	7.984	7.990	7.996	8.002	8.008	8.014	2390
2400	8.014	8.020	8.026	8.032	8.038	8.044	8.051	8.057	8.063	8.069	8.075	2400
2410	8.075	8.081	8.087	8.093	8.099	8.105	8.111	8.118	8.124	8.130	8.136	2410
2420	8.136	8.142	8.148	8.154	8.160	8.166	8.172	8.179	8.185	8.191	8.197	2420
2430	8.197	8.203	8.209	8.215	8.221	8.227	8.234	8.240	8.246	8.252	8.258	2430
2440	8.258	8.264	8.270	8.276	8.283	8.289	8.295	8.301	8.307	8.313	8.319	2440
2450	8.319	8.326	8.332	8.338	8.344	8.350	8.356	8.362	8.369	8.375	8.381	2450
2460	8.381	8.387	8.393	8.399	8.405	8.412	8.418	8.424	8.430	8.436	8.442	2460
2470	8.442	8.449	8.455	8.461	8.467	8.473	8.479	8.486	8.492	8.498	8.504	2470
2480	8.504	8.510	8.516	8.523	8.529	8.535	8.541	8.547	8.554	8.560	8.566	2480
2490	8.566	8.572	8.578	8.585	8.591	8.597	8.603	8.609	8.616	8.622	8.628	2490
2500	8.628	8.634	8.640	8.647	8.653	8.659	8.665	8.671	8.678	8.684	8.690	2500
2510	8.690	8.696	8.702	8.709	8.715	8.721	8.727	8.733	8.740	8.746	8.752	2510
2520	8.752	8.758	8.765	8.771	8.777	8.783	8.790	8.796	8.802	8.808	8.814	2520
2530	8.814	8.821	8.827	8.833	8.839	8.846	8.852	8.858	8.864	8.871	8.877	2530
2540	8.877	8.883	8.889	8.896	8.902	8.908	8.914	8.921	8.927	8.933	8.939	2540
2550	8.939	8.946	8.952	8.958	8.964	8.971	8.977	8.983	8.989	8.996	9.002	2550
2560	9.002	9.008	9.015	9.021	9.027	9.033	9.040	9.046	9.052	9.058	9.065	2560
2570	9.065	9.071	9.077	9.084	9.090	9.096	9.102	9.109	9.115	9.121	9.128	2570
2580	9.128	9.134	9.140	9.146	9.153	9.159	9.165	9.172	9.178	9.184	9.191	2580
2590	9.191	9.197	9.203	9.209	9.216	9.222	9.228	9.235	9.241	9.247	9.254	2590
2600	9.254	9.260	9.266	9.273	9.279	9.285	9.291	9.298	9.304	9.310	9.317	2600
2610	9.317	9.323	9.329	9.336	9.342	9.348	9.355	9.361	9.367	9.374	9.380	2610
2620	9.380	9.386	9.393	9.399	9.405	9.412	9.418	9.424	9.431	9.437	9.443	2620
2630	9.443	9.450	9.456	9.462	9.469	9.475	9.481	9.488	9.494	9.500	9.507	2630

Table 8.1.2 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2640	9.507	9.513	9.519	9.526	9.532	9.538	9.545	9.551	9.558	9.564	9.570	2640
2650	9.570	9.577	9.583	9.589	9.596	9.602	9.608	9.615	9.621	9.627	9.634	2650
2660	9.634	9.640	9.647	9.653	9.659	9.666	9.672	9.678	9.685	9.691	9.697	2660
2670	9.697	9.704	9.710	9.717	9.723	9.729	9.736	9.742	9.748	9.755	9.761	2670
2680	9.761	9.768	9.774	9.780	9.787	9.793	9.800	9.806	9.812	9.819	9.825	2680
2690	9.825	9.831	9.838	9.844	9.851	9.857	9.863	9.870	9.876	9.883	9.889	2690
2700	9.889	9.895	9.902	9.908	9.915	9.921	9.927	9.934	9.940	9.947	9.953	2700
2710	9.953	9.959	9.966	9.972	9.979	9.985	9.991	9.998	10.004	10.011	10.017	2710
2720	10.017	10.023	10.030	10.036	10.043	10.049	10.056	10.062	10.068	10.075	10.081	2720
2730	10.081	10.088	10.094	10.100	10.107	10.113	10.120	10.126	10.133	10.139	10.145	2730
2740	10.145	10.152	10.158	10.165	10.171	10.178	10.184	10.190	10.197	10.203	10.210	2740
2750	10.210	10.216	10.223	10.229	10.235	10.242	10.248	10.255	10.261	10.268	10.274	2750
2760	10.274	10.280	10.287	10.293	10.300	10.306	10.313	10.319	10.325	10.332	10.338	2760
2770	10.338	10.345	10.351	10.358	10.364	10.371	10.377	10.383	10.390	10.396	10.403	2770
2780	10.403	10.409	10.416	10.422	10.429	10.435	10.441	10.448	10.454	10.461	10.467	2780
2790	10.467	10.474	10.480	10.487	10.493	10.500	10.506	10.512	10.519	10.525	10.532	2790
2800	10.532	10.538	10.545	10.551	10.558	10.564	10.571	10.577	10.584	10.590	10.596	2800
2810	10.596	10.603	10.609	10.616	10.622	10.629	10.635	10.642	10.648	10.655	10.661	2810
2820	10.661	10.668	10.674	10.680	10.687	10.693	10.700	10.706	10.713	10.719	10.726	2820
2830	10.726	10.732	10.739	10.745	10.752	10.758	10.765	10.771	10.778	10.784	10.790	2830
2840	10.790	10.797	10.803	10.810	10.816	10.823	10.829	10.836	10.842	10.849	10.855	2840
2850	10.855	10.862	10.868	10.875	10.881	10.888	10.894	10.901	10.907	10.914	10.920	2850
2860	10.920	10.926	10.933	10.939	10.946	10.952	10.959	10.965	10.972	10.978	10.985	2860
2870	10.985	10.991	10.998	11.004	11.011	11.017	11.024	11.030	11.037	11.043	11.050	2870
2880	11.050	11.056	11.063	11.069	11.076	11.082	11.089	11.095	11.102	11.108	11.115	2880
2890	11.115	11.121	11.128	11.134	11.141	11.147	11.154	11.160	11.166	11.173	11.179	2890
2900	11.179	11.186	11.192	11.199	11.205	11.212	11.218	11.225	11.231	11.238	11.244	2900
2910	11.244	11.251	11.257	11.264	11.270	11.277	11.283	11.290	11.296	11.303	11.309	2910
2920	11.309	11.316	11.322	11.329	11.335	11.342	11.348	11.355	11.361	11.368	11.374	2920
2930	11.374	11.381	11.387	11.394	11.400	11.407	11.413	11.420	11.426	11.433	11.439	2930
2940	11.439	11.446	11.452	11.459	11.465	11.472	11.478	11.485	11.491	11.498	11.504	2940
2950	11.504	11.511	11.517	11.524	11.530	11.537	11.543	11.550	11.556	11.563	11.569	2950
2960	11.569	11.576	11.582	11.589	11.595	11.602	11.608	11.615	11.621	11.628	11.634	2960
2970	11.634	11.641	11.647	11.654	11.660	11.667	11.673	11.680	11.686	11.693	11.699	2970
2980	11.699	11.706	11.712	11.719	11.725	11.732	11.738	11.745	11.751	11.758	11.764	2980
2990	11.764	11.771	11.777	11.784	11.790	11.797	11.803	11.810	11.816	11.823	11.829	2990
3000	11.829	11.836	11.842	11.849	11.855	11.862	11.868	11.875	11.881	11.888	11.894	3000
3010	11.894	11.901	11.907	11.914	11.920	11.927	11.933	11.940	11.946	11.953	11.959	3010
3020	11.959	11.966	11.972	11.979	11.985	11.992	11.998	12.005	12.011	12.018	12.024	3020
3030	12.024	12.031	12.037	12.044	12.050	12.057	12.063	12.070	12.076	12.083	12.089	3030
3040	12.089	12.096	12.102	12.109	12.115	12.121	12.128	12.134	12.141	12.147	12.154	3040
3050	12.154	12.160	12.167	12.173	12.180	12.186	12.193	12.199	12.206	12.212	12.219	3050
3060	12.219	12.225	12.232	12.238	12.245	12.251	12.258	12.264	12.271	12.277	12.284	3060
3070	12.284	12.290	12.297	12.303	12.310	12.316	12.323	12.329	12.336	12.342	12.349	3070
3080	12.349	12.355	12.362	12.368	12.374	12.381	12.387	12.394	12.400	12.407	12.413	3080
3090	12.413	12.420	12.426	12.433	12.439	12.446	12.452	12.459	12.465	12.472	12.478	3090
3100	12.478	12.485	12.491	12.498	12.504	12.511	12.517	12.523	12.530	12.536	12.543	3100
3110	12.543	12.549	12.556	12.562	12.569	12.575	12.582	12.588	12.595	12.601	12.608	3110
3120	12.608	12.614	12.621	12.627	12.633	12.640	12.646	12.653	12.659	12.666	12.672	3120
3130	12.672	12.679	12.685	12.692	12.698	12.705	12.711	12.718	12.724	12.730	12.737	3130
3140	12.737	12.743	12.750	12.756	12.763	12.769	12.776	12.782	12.789	12.795	12.801	3140
3150	12.801	12.808	12.814	12.821	12.827	12.834	12.840	12.847	12.853	12.860	12.866	3150
3160	12.866	12.872	12.879	12.885	12.892	12.898	12.905	12.911	12.918	12.924	12.930	3160

Table 8.1.2 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
3170	12.930	12.937	12.943	12.950	12.956	12.963	12.969	12.976	12.982	12.988	12.995	3170
3180	12.995	13.001	13.008	13.014	13.021	13.027	13.034	13.040	13.046	13.053	13.059	3180
3190	13.059	13.066	13.072	13.079	13.085	13.091	13.098	13.104	13.111	13.117	13.124	3190
3200	13.124	13.130	13.136	13.143	13.149	13.156	13.162	13.169	13.175	13.181	13.188	3200
3210	13.188	13.194	13.201	13.207	13.213	13.220	13.226	13.233	13.239	13.246	13.252	3210
3220	13.252	13.258	13.265	13.271	13.278	13.284	13.290	13.297	13.303	13.310	13.316	3220
3230	13.316	13.322	13.329	13.335	13.342	13.348	13.354	13.361	13.367	13.374	13.380	3230
3240	13.380	13.387	13.393	13.399	13.406	13.412	13.418	13.425	13.431	13.438	13.444	3240
3250	13.444	13.450	13.457	13.463	13.470	13.476	13.482	13.489	13.495	13.502	13.508	3250
3260	13.508	13.514	13.521	13.527	13.533	13.540	13.546	13.553	13.559	13.565	13.572	3260
3270	13.572	13.578	13.585	13.591	13.597	13.604	13.610	13.616	13.623	13.629	13.635	3270
3280	13.635	13.642	13.648	13.655	13.661	13.667	13.674	13.680	13.686	13.693	13.699	3280
3290	13.699	13.706	13.712	13.718	13.725	13.731	13.737	13.744	13.750	13.756	13.763	3290
3300	13.763	13.769	13.775	13.782	13.788	13.794	13.801	13.807	13.814			3300

T/C Type E - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.3 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-270	-9.825	-9.833	-9.831	-9.828	-9.825	-9.821	-9.817	-9.813	-9.808	-9.802	-9.797	-270
-260	-9.797	-9.791	-9.784	-9.777	-9.770	-9.762	-9.754	-9.746	-9.737	-9.728	-9.719	-260
-250	-9.719	-9.709	-9.699	-9.688	-9.677	-9.666	-9.654	-9.642	-9.630	-9.617	-9.604	-250
-240	-9.604	-9.591	-9.577	-9.563	-9.549	-9.534	-9.519	-9.503	-9.488	-9.472	-9.455	-240
-230	-9.455	-9.438	-9.421	-9.404	-9.386	-9.368	-9.350	-9.332	-9.313	-9.293	-9.274	-230
-220	-9.274	-9.254	-9.234	-9.214	-9.193	-9.172	-9.151	-9.129	-9.107	-9.085	-9.063	-220
-210	-9.063	-9.040	-9.017	-8.994	-8.971	-8.947	-8.923	-8.899	-8.874	-8.850	-8.824	-210
-200	-8.824	-8.977	-8.774	-8.748	-8.722	-8.696	-8.669	-8.642	-8.615	-8.588	-8.561	-200
-190	-8.561	-8.533	-8.505	-8.477	-8.449	-8.420	-8.391	-8.362	-8.333	-8.303	-8.273	-190
-180	-8.273	-8.243	-8.213	-8.183	-8.152	-8.121	-8.090	-8.058	-8.027	-7.995	-7.963	-180
-170	-7.963	-7.931	-7.898	-7.866	-7.833	-7.800	-7.767	-7.733	-7.699	-7.665	-7.631	-170
-160	-7.631	-7.597	-7.562	-7.528	-7.493	-7.458	-7.422	-7.387	-7.351	-7.315	-7.279	-160
-150	-7.279	-7.243	-7.206	-7.169	-7.132	-7.095	-7.058	-7.020	-6.983	-6.945	-6.907	-150
-140	-6.907	-6.869	-6.830	-6.792	-6.753	-6.714	-6.675	-6.635	-6.596	-6.556	-6.516	-140
-130	-6.516	-6.476	-6.436	-6.395	-6.354	-6.314	-6.273	-6.231	-6.190	-6.149	-6.107	-130
-120	-6.107	-6.065	-6.023	-5.981	-5.938	-5.896	-5.853	-5.810	-5.767	-5.724	-5.680	-120
-110	-5.680	-5.637	-5.593	-5.549	-5.505	-5.460	-5.416	-5.371	-5.327	-5.282	-5.237	-110
-100	-5.237	-5.191	-5.146	-5.100	-5.055	-5.009	-4.963	-4.916	-4.870	-4.824	-4.777	-100
-90	-4.777	-4.730	-4.683	-4.636	-4.588	-4.541	-4.493	-4.446	-4.398	-4.350	-4.301	-90
-80	-4.301	-4.253	-4.204	-4.156	-4.107	-4.058	-4.009	-3.959	-3.910	-3.860	-3.811	-80
-70	-3.811	-3.761	-3.711	-3.661	-3.610	-3.560	-3.509	-3.459	-3.408	-3.357	-3.306	-70
-60	-3.306	-3.254	-3.203	-3.152	-3.100	-3.048	-2.996	-2.944	-2.892	-2.839	-2.787	-60
-50	-2.787	-2.734	-2.681	-2.628	-2.575	-2.522	-2.469	-2.416	-2.362	-2.308	-2.254	-50
-40	-2.254	-2.200	-2.146	-2.092	-2.038	-1.983	-1.929	-1.874	-1.819	-1.764	-1.709	-40
-30	-1.709	-1.654	-1.599	-1.543	-1.487	-1.432	-1.376	-1.320	-1.264	-1.208	-1.151	-30
-20	-1.151	-1.095	-1.038	-0.982	-0.925	-0.868	-0.811	-0.754	-0.696	-0.639	-0.581	-20
-10	-0.581	-0.524	-0.466	-0.408	-0.350	-0.292	-0.234	-0.176	-0.117	-0.059	0.000	-10
0	0.000	0.059	0.118	0.176	0.235	0.295	0.354	0.413	0.472	0.532	0.591	0
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.011	1.071	1.131	1.192	10
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.739	1.801	20

Table 8.1.3 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
30	1.801	1.862	1.924	1.985	2.047	2.109	2.171	2.233	2.295	2.357	2.419	30
40	2.419	2.482	2.544	2.607	2.669	2.732	2.795	2.858	2.921	2.984	3.047	40
50	3.047	3.110	3.173	3.237	3.300	3.364	3.428	3.491	3.555	3.619	3.683	50
60	3.683	3.748	3.812	3.876	3.941	4.005	4.070	4.134	4.199	4.264	4.329	60
70	4.329	4.394	4.459	4.524	4.590	4.655	4.720	4.786	4.852	4.917	4.983	70
80	4.983	5.049	5.115	5.181	5.247	5.314	5.380	5.446	5.513	5.579	5.646	80
90	5.646	5.713	5.780	5.846	5.913	5.981	6.048	6.115	6.182	6.250	6.317	90
100	6.317	6.385	6.452	6.520	6.588	6.656	6.724	6.792	6.860	6.928	6.996	100
110	6.996	7.064	7.133	7.201	7.270	7.339	7.407	7.476	7.545	7.614	7.683	110
120	7.683	7.752	7.821	7.890	7.960	8.029	8.099	8.168	8.238	8.307	8.377	120
130	8.377	8.447	8.517	8.587	8.657	8.727	8.797	8.867	8.938	9.008	9.078	130
140	9.078	9.149	9.220	9.290	9.361	9.432	9.503	9.573	9.644	9.715	9.787	140
150	9.787	9.858	9.929	10.000	10.072	10.143	10.215	10.286	10.358	10.429	10.501	150
160	10.501	10.573	10.645	10.717	10.789	10.861	10.933	11.005	11.077	11.150	11.222	160
170	11.222	11.294	11.367	11.439	11.512	11.585	11.657	11.730	11.803	11.876	11.949	170
180	11.949	12.022	12.095	12.168	12.241	12.314	12.387	12.461	12.534	12.608	12.681	180
190	12.681	12.755	12.828	12.902	12.975	13.049	13.123	13.197	13.271	13.345	13.419	190
200	13.419	13.493	13.567	13.641	13.715	13.789	13.864	13.938	14.012	14.087	14.161	200
210	14.161	14.236	14.310	14.385	14.460	14.534	14.609	14.684	14.759	14.834	14.909	210
220	14.909	14.984	15.059	15.134	15.209	15.284	15.359	15.435	15.510	15.585	15.661	220
230	15.661	15.736	15.812	15.887	15.963	16.038	16.114	16.190	16.266	16.341	16.417	230
240	16.417	16.493	16.569	16.645	16.721	16.797	16.873	16.949	17.025	17.101	17.178	240
250	17.178	17.254	17.330	17.406	17.483	17.559	17.636	17.712	17.789	17.865	17.942	250
260	17.942	18.018	18.095	18.172	18.248	18.325	18.402	18.479	18.556	18.633	18.710	260
270	18.710	18.787	18.864	18.941	19.018	19.095	19.172	19.249	19.326	19.404	19.481	270
280	19.481	19.558	19.636	19.713	19.790	19.868	19.945	20.023	20.100	20.178	20.256	280
290	20.256	20.333	20.411	20.488	20.566	20.644	20.722	20.800	20.877	20.955	21.033	290
300	21.033	21.111	21.189	21.267	21.345	21.423	21.501	21.579	21.657	21.735	21.814	300
310	21.814	21.892	21.970	22.048	22.127	22.205	22.283	22.362	22.440	22.518	22.597	310
320	22.597	22.675	22.754	22.832	22.911	22.989	23.068	23.147	23.225	23.304	23.383	320
330	23.383	23.461	23.540	23.619	23.698	23.777	23.855	23.934	24.013	24.092	24.171	330
340	24.171	24.250	24.329	24.408	24.487	24.566	24.645	24.724	24.803	24.882	24.961	340
350	24.961	25.041	25.120	25.199	25.278	25.357	25.437	25.516	25.595	25.675	25.754	350
360	25.754	25.833	25.913	25.992	26.072	26.151	26.230	26.310	26.389	26.469	26.549	360
370	26.549	26.628	26.708	26.787	26.867	26.947	27.026	27.106	27.186	27.265	27.345	370
380	27.345	27.425	27.504	27.584	27.664	27.744	27.824	27.903	27.983	28.063	28.143	380
390	28.143	28.223	28.303	28.383	28.463	28.543	28.623	28.703	28.783	28.863	28.943	390
400	28.943	29.023	29.103	29.183	29.263	29.343	29.423	29.503	29.584	29.664	29.744	400
410	29.744	29.824	29.904	29.984	30.065	30.145	30.225	30.305	30.386	30.466	30.546	410
420	30.546	30.627	30.707	30.787	30.868	30.948	31.028	31.109	31.189	31.270	31.350	420
430	31.350	31.430	31.511	31.591	31.672	31.752	31.833	31.913	31.994	32.074	32.155	430
440	32.155	32.235	32.316	32.396	32.477	32.557	32.638	32.719	32.799	32.880	32.960	440
450	32.960	33.041	33.122	33.202	33.283	33.364	33.444	33.525	33.605	33.686	33.767	450
460	33.767	33.848	33.928	34.009	34.090	34.170	34.251	34.332	34.413	34.493	34.574	460
470	34.574	34.655	34.736	34.816	34.897	34.978	35.059	35.140	35.220	35.301	35.382	470
480	35.382	35.463	35.544	35.624	35.705	35.786	35.867	35.948	36.029	36.109	36.190	480
490	36.190	36.271	36.352	36.433	36.514	36.595	36.675	36.756	36.837	36.918	36.999	490
500	36.999	37.080	37.161	37.242	37.323	37.403	37.484	37.565	37.646	37.727	37.808	500
510	37.808	37.889	37.970	38.051	38.132	38.213	38.293	38.374	38.455	38.536	38.617	510
520	38.617	38.698	38.779	38.860	38.941	39.022	39.103	39.184	39.264	39.345	39.426	520
530	39.426	39.507	39.588	39.669	39.750	39.831	39.912	39.993	40.074	40.155	40.236	530
540	40.236	40.316	40.397	40.478	40.559	40.640	40.721	40.802	40.883	40.964	41.045	540
550	41.045	41.125	41.206	41.287	41.368	41.449	41.530	41.611	41.692	41.773	41.853	550

Table 8.1.3 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
560	41.853	41.934	42.015	42.096	42.177	42.258	42.339	42.419	42.500	42.581	42.662	560
570	42.662	42.743	42.824	42.904	42.985	43.066	43.147	43.228	43.308	43.389	43.470	570
580	43.470	43.551	43.632	43.712	43.793	43.874	43.955	44.035	44.116	44.197	44.278	580
590	44.278	44.358	44.439	44.520	44.601	44.681	44.762	44.843	44.923	45.004	45.085	590
600	45.085	45.165	45.246	45.327	45.407	45.488	45.569	45.649	45.730	45.811	45.891	600
610	45.891	45.972	46.052	46.133	46.213	46.294	46.375	46.455	46.536	46.616	46.697	610
620	46.697	46.777	46.858	46.938	47.019	47.099	47.180	47.260	47.341	47.421	47.502	620
630	47.502	47.582	47.663	47.743	47.824	47.904	47.984	48.065	48.145	48.226	48.306	630
640	48.306	48.386	48.467	48.547	48.627	48.708	48.788	48.868	48.949	49.029	49.109	640
650	49.109	49.189	49.270	49.350	49.430	49.510	49.591	49.671	49.751	49.831	49.911	650
660	49.911	49.992	50.072	50.152	50.232	50.312	50.392	50.472	50.553	50.633	50.713	660
670	50.713	50.793	50.873	50.953	51.033	51.113	51.193	51.273	51.353	51.433	51.513	670
680	51.513	51.593	51.673	51.753	51.833	51.913	51.993	52.073	52.152	52.232	52.312	680
690	52.312	52.392	52.472	52.552	52.632	52.711	52.791	52.871	52.951	53.031	53.110	690
700	53.110	53.190	53.270	53.350	53.429	53.509	53.589	53.668	53.748	53.828	53.907	700
710	53.907	53.987	54.066	54.146	54.226	54.305	54.385	54.464	54.544	54.623	54.703	710
720	54.703	54.782	54.862	54.941	55.021	55.100	55.180	55.259	55.339	55.418	55.498	720
730	55.498	55.577	55.656	55.736	55.815	55.894	55.974	56.053	56.132	56.212	56.291	730
740	56.291	56.370	56.449	56.529	56.608	56.687	56.766	56.845	56.924	57.004	57.083	740
750	57.083	57.162	57.241	57.320	57.399	57.478	57.557	57.636	57.715	57.794	57.873	750
760	57.873	57.952	58.031	58.110	58.189	58.268	58.347	58.426	58.505	58.584	58.663	760
770	58.663	58.742	58.820	58.899	58.978	59.057	59.136	59.214	59.293	59.372	59.451	770
780	59.451	59.529	59.608	59.687	59.765	59.844	59.923	60.001	60.080	60.159	60.237	780
790	60.237	60.316	60.394	60.473	60.551	60.630	60.708	60.787	60.865	60.944	61.022	790
800	61.022	61.101	61.179	61.258	61.336	61.414	61.493	61.571	61.649	61.728	61.806	800
810	61.806	61.884	61.962	62.041	62.119	62.197	62.275	62.353	62.432	62.510	62.588	810
820	62.588	62.666	62.744	62.822	62.900	62.978	63.056	63.134	63.212	63.290	63.368	820
830	63.368	63.446	63.524	63.602	63.680	63.758	63.836	63.914	63.992	64.069	64.147	830
840	64.147	64.225	64.303	64.380	64.458	64.536	64.614	64.691	64.769	64.847	64.924	840
850	64.924	65.002	65.080	65.157	65.235	65.312	65.390	65.467	65.545	65.622	65.700	850
860	65.700	65.777	65.855	65.932	66.009	66.087	66.164	66.241	66.319	66.396	66.473	860
870	66.473	66.551	66.628	66.705	66.782	66.859	66.937	67.014	67.091	67.168	67.245	870
880	67.245	67.322	67.399	67.476	67.553	67.630	67.707	67.784	67.861	67.938	68.015	880
890	68.015	68.092	68.169	68.246	68.323	68.399	68.476	68.553	68.630	68.706	68.783	890
900	68.783	68.860	68.936	69.013	69.090	69.166	69.243	69.320	69.396	69.473	69.549	900
910	69.549	69.626	69.702	69.779	69.855	69.931	70.008	70.084	70.161	70.237	70.313	910
920	70.313	70.390	70.466	70.542	70.618	70.694	70.771	70.847	70.923	70.999	71.075	920
930	71.075	71.151	71.227	71.304	71.380	71.456	71.532	71.608	71.683	71.759	71.835	930
940	71.835	71.911	71.987	72.063	72.139	72.215	72.290	72.366	72.442	72.518	72.593	940
950	72.593	72.669	72.745	72.820	72.896	72.972	73.047	73.123	73.199	73.274	73.350	950
960	73.350	73.425	73.501	73.576	73.652	73.727	73.802	73.878	73.953	74.029	74.104	960
970	74.104	74.179	74.255	74.330	74.405	74.480	74.556	74.631	74.706	74.781	74.857	970
980	74.857	74.932	75.007	75.082	75.157	75.232	75.307	75.382	75.458	75.533	75.608	980
990	75.608	75.683	75.758	75.833	75.908	75.983	76.058	76.133	76.208	76.283	76.358	990

T/C Type E - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.4 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-460							-9.835	-9.834	-9.833	-9.832	-9.830	-460
-450	-9.830	-9.829	-9.827	-9.825	-9.823	-9.821	-9.819	-9.817	-9.814	-9.812	-9.809	-450
-440	-9.809	-9.806	-9.803	-9.800	-9.797	-9.793	-9.790	-9.786	-9.783	-9.779	-9.775	-440
-430	-9.778	-9.771	-9.767	-9.762	-9.758	-9.753	-9.749	-9.744	-9.739	-9.734	-9.729	-430
-420	-9.729	-9.724	-9.719	-9.713	-9.708	-9.702	-9.696	-9.690	-9.684	-9.678	-9.672	-420
-410	-9.672	-9.666	-9.659	-9.653	-9.646	-9.639	-9.633	-9.626	-9.619	-9.611	-9.604	-410
-400	-9.604	-9.597	-9.589	-9.582	-9.574	-9.566	-9.558	-9.550	-9.542	-9.534	-9.526	-400
-390	-9.526	-9.517	-9.509	-9.500	-9.491	-9.482	-9.473	-9.464	-9.455	-9.446	-9.437	-390
-380	-9.437	-9.427	-9.418	-9.408	-9.398	-9.388	-9.378	-9.368	-9.358	-9.348	-9.338	-380
-370	-9.338	-9.327	-9.317	-9.306	-9.296	-9.285	-9.274	-9.263	-9.252	-9.241	-9.229	-370
-360	-9.229	-9.218	-9.207	-9.195	-9.184	-9.172	-9.130	-9.148	-9.136	-9.124	-9.112	-360
-350	-9.112	-9.100	-9.088	-9.075	-9.063	-9.050	-9.038	-9.025	-9.012	-8.999	-8.986	-350
-340	-8.986	-8.973	-8.960	-8.947	-8.934	-8.920	-8.907	-8.893	-8.880	-8.866	-8.852	-340
-330	-8.852	-8.838	-8.824	-8.810	-8.796	-8.782	-8.768	-8.754	-8.739	-8.725	-8.710	-330
-320	-8.710	-8.696	-8.681	-8.666	-8.651	-8.636	-8.621	-8.606	-8.591	-8.576	-8.561	-320
-310	-8.561	-8.545	-8.530	-8.514	-8.499	-8.483	-8.468	-8.452	-8.436	-8.420	-8.404	-310
-300	-8.404	-8.388	-8.372	-8.355	-8.339	-8.323	-8.306	-8.290	-8.273	-8.257	-8.240	-300
-29	-8.240	-8.223	-8.206	-8.189	-8.172	-8.155	-8.138	-8.121	-8.104	-8.086	-8.069	-290
-280	-8.069	-8.051	-8.034	-8.016	-7.999	-7.981	-7.963	-7.945	-7.927	-7.909	-7.891	-280
-270	-7.891	-7.873	-7.855	-7.837	-7.818	-7.800	-7.781	-7.763	-7.744	-7.726	-7.707	-270
-260	-7.707	-7.688	-7.669	-7.650	-7.631	-7.612	-7.593	-7.574	-7.555	-7.535	-7.516	-260
-250	-7.516	-7.497	-7.477	-7.458	-7.438	-7.418	-7.399	-7.379	-7.359	-7.339	-7.319	-250
-240	-7.319	-7.299	-7.279	-7.259	-7.239	-7.218	-7.198	-7.178	-7.157	-7.137	-7.116	-240
-230	-7.116	-7.095	-7.075	-7.054	-7.033	-7.012	-6.991	-6.970	-6.949	-6.928	-6.907	-230
-220	-6.907	-6.886	-6.864	-6.843	-6.822	-6.800	-6.779	-6.757	-6.735	-6.714	-6.692	-220
-210	-6.692	-6.670	-6.648	-6.626	-6.604	-6.582	-6.560	-6.538	-6.516	-6.494	-6.471	-210
-200	-6.471	-6.449	-6.427	-6.404	-6.382	-6.359	-6.336	-6.314	-6.291	-6.268	-6.245	-200
-190	-6.245	-6.222	-6.199	-6.176	-6.153	-6.130	-6.107	-6.084	-6.060	-6.037	-6.013	-190
-180	-6.013	-5.990	-5.967	-5.943	-5.919	-5.896	-5.872	-5.848	-5.824	-5.800	-5.776	-180
-170	-5.776	-5.752	-5.728	-5.704	-5.680	-5.656	-5.632	-5.607	-5.583	-5.559	-5.534	-170
-160	-5.534	-5.540	-5.485	-5.460	-5.436	-5.411	-5.386	-5.362	-5.337	-5.312	-5.287	-160
-150	-5.287	-5.262	-5.237	-5.212	-5.186	-5.161	-5.136	-5.111	-5.085	-5.060	-5.034	-150
-140	-5.034	-5.009	-4.983	-4.958	-4.932	-4.906	-4.880	-4.855	-4.829	-4.803	-4.777	-140
-130	-4.777	-4.751	-4.725	-4.699	-4.672	-4.646	-4.620	-4.594	-4.567	-4.541	-4.515	-130
-120	-4.515	-4.488	-4.462	-4.435	-4.408	-4.382	-4.355	-4.328	-4.301	-4.274	-4.248	-120
-110	-4.248	-4.221	-4.194	-4.167	-4.139	-4.112	-4.085	-4.058	-4.031	-4.003	-3.976	-110
-100	-3.976	-3.949	-3.921	-3.894	-3.866	-3.838	-3.811	-3.783	-3.755	-3.728	-3.700	-100
-90	-3.700	-3.672	-3.644	-3.616	-3.588	-3.560	-3.532	-3.504	-3.476	-3.447	-3.419	-90
-80	-3.419	-3.391	-3.363	-3.334	-3.306	-3.277	-3.249	-3.220	-3.192	-3.163	-3.134	-80
-70	-3.134	-3.106	-3.077	-3.048	-3.019	-2.990	-2.961	-2.932	-2.903	-2.874	-2.845	-70
-60	-2.845	-2.816	-2.787	-2.758	-2.728	-2.699	-2.670	-2.640	-2.611	-2.581	-2.552	-60
-50	-2.552	-2.522	-2.493	-2.463	-2.433	-2.404	-2.374	-2.344	-2.314	-2.284	-2.254	-50
-40	-2.254	-2.224	-2.194	-2.164	-2.134	-2.104	-2.074	-2.044	-2.014	-1.983	-1.953	-40
-30	-1.953	-1.923	-1.892	-1.862	-1.831	-1.801	-1.770	-1.740	-1.709	-1.678	-1.648	-30
-20	-1.648	-1.617	-1.586	-1.555	-1.525	-1.494	-1.463	-1.432	-1.401	-1.370	-1.339	-20
-10	-1.339	-1.308	-1.276	-1.245	-1.214	-1.183	-1.151	-1.120	-1.089	-1.057	-1.026	-10
0	-1.026	-0.994	-0.963	-0.931	-0.900	-0.868	-0.836	-0.805	-0.773	-0.741	-0.709	0

Table 8.1.4 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
10	-0.709	-0.677	-0.645	-0.613	-0.581	-0.549	-0.517	-0.485	-0.453	-0.421	-0.389	10
20	-0.389	-0.357	-0.324	-0.292	-0.260	-0.227	-0.195	-0.163	-0.130	-0.098	-0.065	20
30	-0.065	-0.033	0.000	0.033	0.065	0.098	0.131	0.163	0.196	0.229	0.262	30
40	0.262	0.295	0.327	0.360	0.393	0.426	0.459	0.492	0.525	0.558	0.591	40
50	0.591	0.624	0.658	0.691	0.724	0.757	0.790	0.824	0.857	0.890	0.924	50
60	0.924	0.957	0.990	1.024	1.057	1.091	1.124	1.158	1.192	1.225	1.259	60
70	1.259	1.292	1.326	1.360	1.394	1.427	1.461	1.495	1.529	1.563	1.597	70
80	1.597	1.631	1.665	1.699	1.733	1.767	1.801	1.835	1.869	1.903	1.937	80
90	1.937	1.972	2.006	2.040	2.075	2.109	2.143	2.178	2.212	2.247	2.281	90
100	2.281	2.316	2.350	2.385	2.419	2.454	2.489	2.523	2.558	2.593	2.627	100
110	2.627	2.662	2.697	2.732	2.767	2.802	2.837	2.872	2.907	2.942	2.977	110
120	2.977	3.012	3.047	3.082	3.117	3.152	3.187	3.223	3.258	3.293	3.329	120
130	3.329	3.364	3.399	3.435	3.470	3.506	3.541	3.577	3.612	3.648	3.683	130
140	3.683	3.719	3.755	3.790	3.826	3.862	3.898	3.933	3.969	4.005	4.041	140
150	4.041	4.077	4.113	4.149	4.185	4.221	4.257	4.293	4.329	4.365	4.401	150
160	4.401	4.437	4.474	4.510	4.546	4.582	4.619	4.655	4.691	4.728	4.764	160
170	4.764	4.801	4.837	4.874	4.910	4.947	4.983	5.020	5.056	5.093	5.130	170
180	5.130	5.166	5.203	5.240	5.277	5.314	5.350	5.387	5.424	5.461	5.498	180
190	5.498	5.535	5.572	5.609	5.646	5.683	5.720	5.757	5.794	5.832	5.869	190
200	5.869	5.906	5.943	5.981	6.018	6.055	6.092	6.130	6.167	6.205	6.242	200
210	6.242	6.280	6.317	6.355	6.392	6.430	6.467	6.505	6.543	6.580	6.618	210
220	6.618	6.656	6.693	6.731	6.769	6.807	6.845	6.882	6.920	6.958	6.996	220
230	6.996	7.034	7.072	7.110	7.148	7.186	7.224	7.262	7.300	7.339	7.377	230
240	7.377	7.415	7.453	7.491	7.530	7.568	7.606	7.645	7.683	7.721	7.760	240
250	7.760	7.798	7.837	7.875	7.914	7.952	7.991	8.029	8.068	8.106	8.145	250
260	8.145	8.184	8.222	8.261	8.300	8.338	8.377	8.416	8.455	8.494	8.532	260
270	8.532	8.571	8.610	8.649	8.688	8.727	8.766	8.805	8.844	8.883	8.922	270
280	8.922	8.961	9.000	9.039	9.078	9.118	9.157	9.196	9.235	9.274	9.314	280
290	9.314	9.353	9.392	9.432	9.471	9.510	9.550	9.589	9.629	9.668	9.708	290
300	9.708	9.747	9.787	9.826	9.866	9.905	9.945	9.984	10.024	10.064	10.103	300
310	10.103	10.143	10.183	10.223	10.262	10.302	10.342	10.382	10.421	10.461	10.501	310
320	10.501	10.541	10.581	10.621	10.661	10.701	10.741	10.781	10.821	10.861	10.901	320
330	10.901	10.941	10.981	11.021	11.061	11.101	11.142	11.182	11.222	11.262	11.302	330
340	11.302	11.343	11.383	11.423	11.464	11.504	11.544	11.585	11.625	11.665	11.706	340
350	11.706	11.746	11.787	11.827	11.868	11.908	11.949	11.989	12.030	12.070	12.111	350
360	12.111	12.152	12.192	12.233	12.273	12.314	12.355	12.396	12.436	12.477	12.518	360
370	12.518	12.559	12.599	12.640	12.681	12.722	12.763	12.804	12.844	12.885	12.926	370
380	12.926	12.967	13.008	13.049	13.090	13.131	13.172	13.213	13.254	13.295	13.336	380
390	13.336	13.378	13.419	13.460	13.501	13.542	13.583	13.624	13.666	13.707	13.748	390
400	13.748	13.789	13.831	13.872	13.913	13.955	13.996	14.037	14.079	14.120	14.161	400
410	14.161	14.203	14.244	14.286	14.327	14.368	14.410	14.451	14.493	14.534	14.576	410
420	14.576	14.618	14.659	14.701	14.742	14.784	14.826	14.867	14.909	14.950	14.992	420
430	14.992	15.034	15.076	15.117	15.159	15.201	15.243	15.284	15.326	15.368	15.410	430
440	15.410	15.451	15.493	15.535	15.577	15.619	15.661	15.703	15.745	15.787	15.829	440
450	15.829	15.871	15.912	15.954	15.996	16.038	16.080	16.123	16.165	16.207	16.249	450
460	16.249	16.291	16.333	16.375	16.417	16.459	16.501	16.544	16.586	16.628	16.670	460
470	16.670	16.712	16.755	16.797	16.839	16.881	16.924	16.966	17.008	17.051	17.093	470
480	17.093	17.135	17.178	17.220	17.262	17.305	17.347	17.389	17.432	17.474	17.517	480
490	17.517	17.559	17.602	17.644	17.687	17.729	17.772	17.814	17.857	17.899	17.942	490
500	17.942	17.984	18.027	18.070	18.112	18.155	18.197	18.240	18.283	18.325	18.368	500
510	18.368	18.411	18.453	18.496	18.539	18.581	18.624	18.667	18.710	18.752	18.795	510
520	18.795	18.838	18.881	18.924	18.966	19.009	19.052	19.095	19.138	19.181	19.223	520
530	19.223	19.266	19.309	19.352	19.395	19.438	19.481	19.524	19.567	19.610	19.653	530

Table 8.1.4 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
540	19.653	19.696	19.739	19.782	19.825	19.868	19.911	19.954	19.997	20.040	20.083	540
550	20.083	20.126	20.169	20.212	20.256	20.299	20.342	20.385	20.428	20.471	20.514	550
560	20.514	20.558	20.601	20.644	20.687	20.730	20.774	20.817	20.860	20.903	20.947	560
570	20.947	20.990	21.033	21.076	21.120	21.163	21.206	21.250	21.293	21.336	21.380	570
580	21.380	21.423	21.466	21.510	21.553	21.597	21.640	21.683	21.727	21.770	21.814	580
590	21.814	21.857	21.901	21.944	21.987	22.031	22.074	22.118	22.161	22.205	22.248	590
600	22.248	22.292	22.336	22.379	22.423	22.466	22.510	22.553	22.597	22.640	22.684	600
610	22.684	22.728	22.771	22.815	22.859	22.902	22.946	22.989	23.033	23.077	23.120	610
620	23.120	23.164	23.208	23.252	23.295	23.339	23.383	23.426	23.470	23.514	23.558	620
630	23.558	23.601	23.645	23.689	23.733	23.777	23.820	23.864	23.908	23.952	23.996	630
640	23.996	24.039	24.083	24.127	24.171	24.15	24.259	24.302	24.346	24.390	24.434	640
650	24.434	24.478	24.522	24.566	24.610	24.6554	24.698	24.742	24.786	24.829	24.873	650
660	24.873	24.917	24.961	25.005	25.049	25.093	25.137	25.181	25.225	25.269	25.313	660
670	25.313	25.357	25.401	25.445	25.490	25.534	25.578	25.622	25.666	25.710	25.754	670
680	25.754	25.798	25.842	25.886	25.930	25.74	26.019	26.063	26.107	26.151	26.195	680
690	26.195	26.239	26.283	26.328	26.372	26.416	26.460	26.504	26.549	26.593	26.637	690
700	26.637	26.681	26.725	26.770	26.814	26.858	26.902	26.947	26.991	27.035	27.079	700
710	27.079	27.124	27.168	27.212	27.256	27.301	27.345	27.389	27.434	27.478	27.522	710
720	27.522	27.566	27.611	27.655	27.699	27.744	27.788	27.832	27.877	27.921	27.966	720
730	27.966	28.010	28.054	28.099	28.143	28.187	28.232	28.276	28.321	28.365	28.409	730
740	28.409	28.454	28.498	28.543	28.587	28.632	28.676	28.720	28.765	28.809	28.854	740
750	28.854	28.898	28.943	28.987	29.032	29.076	29.121	29.165	29.210	29.254	29.299	750
760	29.299	29.343	29.388	29.432	29.477	29.521	29.566	29.610	29.655	29.699	29.744	760
770	29.744	29.788	29.833	29.878	29.922	29.967	30.011	30.056	30.100	30.145	30.190	770
780	30.190	30.234	30.279	30.323	30.368	30.412	30.457	30.502	30.546	30.591	30.636	780
790	30.636	30.680	30.725	30.769	30.814	30.859	30.903	30.948	30.993	31.037	31.082	790
800	31.082	31.127	31.171	31.216	31.261	31.305	31.350	31.395	31.439	31.484	31.529	800
810	31.529	31.573	31.618	31.663	31.707	31.752	31.797	31.842	31.886	31.931	31.976	810
820	31.976	32.020	32.065	32.110	32.155	32.199	32.244	32.289	32.334	32.378	32.423	820
830	32.423	32.468	32.513	32.557	32.602	32.647	32.692	32.736	32.781	32.826	32.871	830
840	32.871	32.916	32.960	33.005	33.050	33.095	33.140	33.184	33.229	33.274	33.319	840
850	33.319	33.364	33.408	33.453	33.498	33.543	33.588	33.632	33.677	33.722	33.767	850
860	33.767	33.812	33.857	33.901	33.946	33.991	34.036	34.081	34.126	34.170	34.215	860
870	34.215	34.260	34.305	34.350	34.395	34.440	34.484	34.529	34.574	34.619	34.664	870
880	34.664	34.709	34.754	34.798	34.843	34.888	34.933	34.978	35.023	35.068	35.113	880
890	35.113	35.157	35.202	35.247	35.292	35.337	35.382	35.427	35.472	35.517	35.562	890
900	35.562	35.606	35.651	35.696	35.741	35.786	35.831	35.876	35.921	35.966	36.011	900
910	36.011	36.056	36.100	36.145	36.190	36.235	36.280	36.325	36.370	36.415	36.460	910
920	36.460	36.505	36.550	36.595	36.640	36.684	36.729	36.774	36.819	36.864	36.909	920
930	36.909	36.954	36.999	37.044	37.089	37.134	37.179	37.224	37.269	37.314	37.358	930
940	37.358	37.403	37.448	37.493	37.538	37.583	37.628	37.673	37.718	37.763	37.808	940
950	37.808	37.853	37.898	37.943	37.988	38.033	38.078	38.123	38.168	38.213	38.257	950
960	38.257	38.302	38.347	38.392	38.437	38.482	38.527	38.572	38.617	38.662	38.707	960
970	38.707	38.752	38.797	38.842	38.887	38.932	38.977	39.022	39.067	39.112	39.157	970
980	39.157	39.202	39.247	39.291	39.336	39.381	39.426	39.471	39.516	39.561	39.606	980
990	39.606	39.651	39.696	39.741	39.786	39.831	39.876	39.921	39.966	40.011	40.056	990
1000	40.056	40.101	40.146	40.191	40.236	40.280	40.325	40.370	40.415	40.460	40.505	1000
1010	40.505	40.550	40.595	40.640	40.685	40.730	40.775	40.820	40.865	40.910	40.955	1010
1020	40.955	41.000	41.045	41.090	41.134	41.179	41.224	41.269	41.314	41.359	41.404	1020
1030	41.404	41.449	41.494	41.539	41.584	41.629	41.674	41.719	41.764	41.808	41.853	1030
1040	41.853	41.898	41.943	41.988	42.033	42.078	42.123	42.168	42.213	42.258	42.303	1040
1050	42.303	42.348	42.392	42.437	42.482	42.527	42.572	42.617	42.662	42.707	42.752	1050
1060	42.752	42.797	42.842	42.886	42.931	42.976	43.021	43.066	43.111	43.156	43.201	1060

Table 8.1.4 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1070	43.201	43.246	43.290	43.335	43.380	43.425	43.470	43.515	43.560	43.605	43.650	1070
1080	43.650	43.694	43.739	43.784	43.829	43.874	43.919	43.964	44.008	44.053	44.098	1080
1090	44.098	44.143	44.188	44.233	44.278	44.322	44.367	44.412	44.457	44.502	44.547	1090
1100	44.547	44.592	44.636	44.681	44.726	44.771	44.816	44.861	44.905	44.950	44.995	1100
1110	44.995	45.040	45.085	45.130	45.174	45.219	45.264	45.309	45.354	45.398	45.443	1110
1120	45.443	45.488	45.533	45.578	45.622	45.667	45.712	45.757	45.802	45.846	45.891	1120
1130	45.891	45.936	45.981	46.025	46.070	46.115	46.160	46.205	46.249	46.294	46.339	1130
1140	46.339	46.384	46.428	46.473	46.518	46.563	46.607	46.652	46.697	46.742	46.786	1140
1150	46.786	46.831	46.876	46.921	46.965	47.010	47.055	47.099	47.144	47.189	47.234	1150
1160	47.234	47.278	47.323	47.368	47.412	47.457	47.502	47.546	47.591	47.636	47.681	1160
1170	47.681	47.725	47.770	47.815	47.859	47.904	47.949	47.993	48.038	48.083	48.127	1170
1180	48.127	48.172	48.217	48.261	48.306	48.351	48.395	48.440	48.484	48.529	48.574	1180
1190	48.574	48.618	48.663	48.708	48.752	48.797	48.842	48.886	48.931	48.975	49.020	1190
1200	49.020	49.065	49.109	49.154	49.198	49.243	49.288	49.332	49.377	49.421	49.466	1200
1210	49.466	49.510	49.555	49.600	49.644	49.689	49.733	49.778	49.822	49.867	49.911	1210
1220	49.911	49.956	50.001	50.045	50.090	50.134	50.179	50.223	50.268	50.312	50.357	1220
1230	50.357	50.401	50.446	50.490	50.535	50.579	50.624	50.668	50.713	50.757	50.802	1230
1240	50.802	50.846	50.891	50.935	50.980	51.024	51.069	51.113	51.157	51.202	51.246	1240
1250	51.246	51.291	51.335	51.380	51.424	51.469	51.513	51.557	51.602	51.646	51.691	1250
1260	51.691	51.735	51.780	51.824	51.868	51.913	51.957	52.002	52.046	52.090	52.135	1260
1270	52.135	52.179	52.223	52.268	52.312	52.357	52.401	52.445	52.490	52.534	52.578	1270
1280	52.578	52.623	52.667	52.711	52.756	52.800	52.844	52.889	52.933	52.977	53.022	1280
1290	53.022	53.066	53.110	53.155	53.199	53.243	53.288	53.332	53.376	53.420	53.465	1290
1300	53.465	53.509	53.553	53.597	53.642	53.686	53.730	53.774	53.819	53.863	53.907	1300
1310	53.907	53.951	53.996	54.040	54.084	54.128	54.173	54.217	54.261	54.305	54.349	1310
1320	54.349	54.394	54.438	54.482	54.526	54.570	54.615	54.659	54.703	54.747	54.791	1320
1330	54.791	54.835	54.880	54.924	54.968	55.012	55.056	55.100	55.145	55.189	55.233	1330
1340	55.233	55.277	55.321	55.365	55.409	55.453	55.498	55.542	55.586	55.630	55.674	1340
1350	55.674	55.718	55.762	55.806	55.850	55.894	55.938	55.982	56.026	56.071	56.115	1350
1360	56.115	56.159	56.203	56.247	56.291	56.335	56.379	56.423	56.467	56.511	56.555	1360
1370	56.555	56.599	56.643	56.687	56.731	56.775	56.819	56.863	56.907	56.951	56.995	1370
1380	56.995	57.039	57.083	57.127	57.171	57.215	57.259	57.303	57.346	57.390	57.434	1380
1390	57.434	57.478	57.522	57.566	57.610	57.654	57.698	57.742	57.786	57.830	57.873	1390
1400	57.873	57.917	57.961	58.005	58.049	58.093	58.137	58.181	58.224	58.268	58.312	1400
1410	58.312	58.356	58.400	58.444	58.487	58.531	58.575	58.619	58.663	58.707	58.750	1410
1420	58.750	58.794	58.838	58.882	58.926	58.969	59.013	59.057	59.101	59.144	59.188	1420
1430	59.188	59.232	59.276	59.319	59.363	59.407	59.451	59.494	59.538	59.582	59.626	1430
1440	59.626	59.669	59.713	59.757	59.800	59.844	59.888	59.932	59.975	60.019	60.063	1440
1450	60.063	60.106	60.150	60.194	60.237	60.281	60.325	60.368	60.412	60.455	60.499	1450
1460	60.499	60.543	60.586	60.630	60.674	60.717	60.761	60.804	60.848	60.892	60.935	1460
1470	60.935	60.979	61.022	61.066	61.109	61.153	61.197	61.240	61.284	61.327	61.371	1470
1480	61.371	61.414	61.458	61.501	61.545	61.588	61.632	61.675	61.719	61.762	61.806	1480
1490	61.806	61.849	61.893	61.936	61.980	62.023	62.067	62.110	62.154	62.197	62.240	1490
1500	62.240	62.284	62.327	62.371	62.414	62.458	62.501	62.44	62.588	62.631	62.675	1500
1510	62.675	62.718	62.761	62.805	62.848	62.892	62.935	62.978	63.022	63.065	63.108	1510
1520	63.108	63.152	63.195	63.238	63.282	63.325	63.368	63.412	63.455	63.498	63.542	1520
1530	63.542	63.585	63.658	63.671	63.715	63.758	63.801	63.844	63.888	63.931	63.974	1530
1540	63.974	64.017	64.061	64.104	64.147	64.190	64.234	64.277	64.320	64.363	64.406	1540
1550	64.406	64.450	64.493	64.536	64.579	64.622	64.665	64.709	64.752	64.795	64.838	1550
1560	64.838	64.881	64.924	64.967	65.011	65.054	65.097	65.140	65.183	65.226	65.269	1560
1570	65.269	65.312	65.355	65.398	65.441	65.484	65.528	65.571	65.614	65.657	65.700	1570
1580	65.700	65.743	65.786	65.829	65.872	65.915	65.958	66.001	66.044	66.087	66.130	1580
1590	66.130	66.173	66.216	66.259	66.302	66.345	66.387	66.430	66.473	66.516	66.559	1590

Table 8.1.4 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1600	66.559	66.602	66.645	66.688	66.731	66.774	66.817	66.859	66.902	66.945	66.988	1600
1610	66.988	67.031	67.074	67.117	67.159	67.202	67.245	67.288	67.331	67.374	67.416	1610
1620	67.416	67.459	67.502	67.545	67.588	67.630	67.673	67.716	67.759	67.801	67.844	1620
1630	67.844	67.887	67.930	67.972	68.015	68.058	68.101	68.143	68.186	68.229	68.271	1630
1640	68.271	68.314	68.357	68.399	68.442	68.485	68.527	68.570	68.613	68.655	68.698	1640
1650	68.698	68.740	68.783	68.826	68.868	68.911	68.953	68.996	69.039	69.081	69.124	1650
1660	69.124	69.166	69.209	69.251	69.294	69.337	69.379	69.422	69.464	69.507	69.549	1660
1670	69.549	69.592	69.634	69.677	69.719	69.762	69.804	69.847	69.889	69.931	69.974	1670
1680	69.974	70.016	70.059	70.101	70.144	70.186	70.228	70.271	70.313	70.356	70.398	1680
1690	70.398	70.440	70.483	70.525	70.567	70.610	70.652	70.694	70.737	70.779	70.821	1690
1700	70.821	70.864	70.906	70.948	70.991	71.033	71.075	71.118	71.160	71.202	71.244	1700
1710	71.244	71.287	71.329	71.371	71.413	71.456	71.498	71.540	71.582	71.624	71.667	1710
1720	71.667	71.709	71.751	71.793	71.835	71.878	71.920	71.962	72.004	72.046	72.088	1720
1730	72.088	72.130	72.173	72.215	72.257	72.299	72.341	72.383	72.425	72.467	72.509	1730
1740	72.509	72.551	72.593	72.635	72.678	72.720	72.762	72.804	72.846	72.888	72.930	1740
1750	72.930	72.972	73.014	73.056	73.098	73.140	73.182	73.224	73.266	73.308	73.350	1750
1760	73.350	73.392	73.434	73.475	73.517	73.559	73.601	73.643	73.685	73.727	73.769	1760
1770	73.769	73.811	73.853	73.895	73.936	73.978	74.020	74.062	74.104	74.146	74.188	1770
1780	74.188	74.229	74.271	74.313	74.355	74.397	74.439	74.480	74.522	74.564	74.606	1780
1790	74.606	74.648	74.689	74.731	74.773	74.815	74.857	74.898	74.940	74.982	75.024	1790
1800	75.024	75.065	75.107	75.149	75.191	75.232	75.274	75.316	75.357	75.399	75.441	1800
1810	75.441	75.483	75.524	75.566	75.608	75.649	75.691	75.733	75.774	75.816	75.858	1810
1820	75.858	75.899	75.941	75.983	76.024	76.066	76.108	76.149	76.191	76.233	76.274	1820
1830	76.274	76.316	76.358									1830

T/C Type J - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.5 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-210	-8.096	-8.076	-8.057	-8.037	-8.017	-7.996	-7.976	-7.955	-7.934	-7.912	-7.890	-210
-200	-7.890	-7.868	-7.846	-7.824	-7.801	-7.778	-7.755	-7.731	-7.707	-7.683	-7.659	-200
-190	-7.659	-7.634	-7.609	-7.584	-7.559	-7.533	-7.508	-7.482	-7.455	-7.429	-7.402	-190
-180	-7.402	-7.375	-7.348	-7.321	-7.293	-7.265	-7.237	-7.209	-7.180	-7.151	-7.122	-180
-170	-7.122	-7.093	-7.064	-7.034	-7.004	-6.974	-6.944	-6.914	-6.883	-6.852	-6.821	-170
-160	-6.821	-6.790	-6.758	-6.727	-6.695	-6.663	-6.630	-6.598	-6.565	-6.532	-6.499	-160
-150	-6.499	-6.466	-6.433	-6.399	-6.365	-6.331	-6.297	-6.263	-6.228	-6.194	-6.159	-150
-140	-6.159	-6.124	-6.089	-6.053	-6.018	-5.982	-5.946	-5.910	-5.874	-5.837	-5.801	-140
-130	-5.801	-5.764	-5.727	-5.690	-5.653	-5.615	-5.578	-5.540	-5.502	-5.464	-5.426	-130
-120	-5.426	-5.388	-5.349	-5.311	-5.272	-5.233	-5.194	-5.155	-5.115	-5.076	-5.036	-120
-110	-5.036	-4.996	-4.956	-4.916	-4.876	-4.836	-4.795	-4.755	-4.714	-4.673	-4.632	-110
-100	-4.632	-4.591	-4.550	-4.508	-4.467	-4.425	-4.383	-4.341	-4.299	-4.257	-4.215	-100
-90	-4.215	-4.172	-4.130	-4.087	-4.044	-4.001	-3.958	-3.915	-3.872	-3.829	-3.785	-90
-80	-3.785	-3.742	-3.698	-3.654	-3.610	-3.566	-3.522	-3.478	-3.433	-3.389	-3.344	-80
-70	-3.344	-3.299	-3.255	-3.210	-3.165	-3.120	-3.074	-3.029	-2.984	-2.938	-2.892	-70
-60	-2.892	-2.847	-2.801	-2.755	-2.709	-2.663	-2.617	-2.570	-2.524	-2.478	-2.431	-60
-50	-2.431	-2.384	-2.338	-2.291	-2.244	-2.197	-2.150	-2.102	-2.055	-2.008	-1.960	-50
-40	-1.960	-1.913	-1.865	-1.818	-1.770	-1.722	-1.674	-1.626	-1.578	-1.530	-1.481	-40
-30	-1.481	-1.433	-1.385	-1.336	-1.288	-1.239	-1.190	-1.141	-1.093	-1.044	-0.995	-30
-20	-0.995	-0.945	-0.896	-0.847	-0.798	-0.748	-0.699	-0.650	-0.600	-0.550	-0.501	-20

Table 8.1.5 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-10	-0.501	-0.451	-0.401	-0.351	-0.301	-0.251	-0.201	-0.151	-0.101	-0.050	0.000	-10
0	0.000	0.050	0.101	0.151	0.202	0.153	0.303	0.354	0.405	0.456	0.507	0
10	0.507	0.558	0.609	0.660	0.711	0.762	0.813	0.865	0.916	0.867	1.019	10
20	1.019	1.070	1.122	1.174	1.225	1.277	1.329	1.381	1.432	1.484	1.536	20
30	1.536	1.588	1.640	1.693	1.745	1.797	1.849	1.901	1.954	2.006	2.058	30
40	2.058	2.111	2.163	2.216	2.268	2.321	2.374	2.426	2.479	2.532	2.585	40
50	2.585	2.638	2.691	2.743	2.796	2.849	2.902	2.956	3.009	3.062	3.115	50
60	3.115	3.168	3.221	3.275	3.328	3.381	3.435	3.488	3.542	3.595	3.649	60
70	3.649	3.702	3.756	3.809	3.863	3.917	3.971	4.024	4.078	4.132	4.186	70
80	4.186	4.239	4.293	4.347	4.401	4.455	4.509	4.563	4.617	4.671	4.725	80
90	4.725	4.780	4.834	4.888	4.942	4.996	5.050	5.105	5.159	5.213	5.268	90
100	5.268	5.322	5.376	5.431	5.485	5.540	5.594	5.649	5.703	5.758	5.812	100
110	5.812	5.867	5.921	5.976	6.031	6.085	6.140	6.195	6.249	6.304	6.359	110
120	6.359	6.414	6.468	6.523	6.578	6.633	6.688	6.742	6.797	6.852	6.907	120
130	6.907	6.962	7.017	7.072	7.127	7.182	7.237	7.292	7.347	7.402	7.457	130
140	7.457	7.512	7.567	7.622	7.677	7.732	7.787	7.843	7.898	7.953	8.008	140
150	8.008	8.063	8.118	8.174	8.229	8.284	8.339	8.394	8.450	8.505	8.560	150
160	8.560	8.616	8.671	8.726	8.781	8.837	8.892	8.947	9.003	9.058	9.113	160
170	9.113	9.169	9.224	9.279	9.335	9.390	9.446	9.501	9.556	9.612	9.667	170
180	9.667	9.723	9.778	9.834	9.889	9.944	10.000	10.055	10.111	10.166	10.222	180
190	10.222	10.277	10.333	10.388	10.444	10.499	10.555	10.610	10.666	10.721	10.777	190
200	10.777	10.832	10.888	10.943	10.999	11.054	11.110	11.165	11.221	11.276	11.332	200
210	11.332	11.387	11.443	11.498	11.554	11.609	11.665	11.720	11.776	11.831	11.887	210
220	11.887	11.943	11.998	12.054	12.109	12.165	12.220	12.276	12.331	12.387	12.442	220
230	12.442	12.498	12.553	12.609	12.664	12.720	12.776	12.831	12.887	12.942	12.998	230
240	12.998	13.053	13.109	13.164	13.220	13.275	13.331	13.386	13.442	13.497	13.553	240
250	13.553	13.608	13.664	13.719	13.775	13.830	13.886	13.941	13.997	14.052	14.108	250
260	14.108	14.163	14.219	14.274	14.330	14.385	14.441	14.496	14.552	14.607	14.663	260
270	14.663	14.718	14.774	14.829	14.885	14.940	14.995	15.051	15.106	15.162	15.217	270
280	15.217	15.273	15.328	15.383	15.439	15.494	15.550	15.605	15.661	15.716	15.771	280
290	15.771	15.827	15.882	15.938	15.993	16.048	16.104	16.159	16.214	16.270	16.325	290
300	16.325	16.380	16.436	16.491	16.547	16.602	16.657	16.713	16.768	16.823	16.879	300
310	16.879	16.934	16.989	17.044	17.100	17.155	17.210	17.266	17.321	17.376	17.432	310
320	17.432	17.487	17.542	17.597	17.653	17.708	17.763	17.818	17.874	17.929	17.984	320
330	17.984	18.039	18.095	18.150	18.205	18.260	18.316	18.371	18.426	18.481	18.537	330
340	18.537	18.592	18.647	18.702	18.757	18.813	18.868	18.923	18.978	19.033	19.089	340
350	19.089	19.144	19.199	19.254	19.309	19.364	19.420	19.475	19.530	19.585	19.640	350
360	19.640	19.695	19.751	19.806	19.861	19.916	19.971	20.026	20.081	20.137	20.192	360
370	20.192	20.247	20.302	20.357	20.412	20.467	20.523	20.578	20.633	20.688	20.743	370
380	20.743	20.798	20.853	20.909	20.964	21.019	21.074	21.129	21.184	21.239	21.295	380
390	21.295	21.350	21.405	21.460	21.515	21.570	21.625	21.680	21.736	21.791	21.846	390
400	21.846	21.901	21.956	22.011	22.066	22.122	22.177	22.232	22.287	22.342	22.397	400
410	22.397	22.453	22.508	22.863	22.618	22.673	22.728	22.784	22.839	22.894	22.949	410
420	22.949	23.004	23.060	23.115	23.170	23.225	23.280	23.336	23.391	23.446	23.501	420
430	23.501	23.556	23.612	23.667	23.722	23.777	23.833	23.888	23.943	23.999	24.054	430
440	24.054	24.109	24.164	24.220	24.275	24.330	24.386	24.441	24.496	24.552	24.607	440
450	24.607	24.662	24.718	24.773	24.829	24.884	24.939	24.995	25.050	25.106	25.161	450
460	25.161	25.217	25.272	25.327	25.383	25.438	25.494	25.549	25.605	25.661	25.716	460
470	25.716	25.772	25.827	25.883	25.938	25.994	26.050	26.105	26.161	26.216	26.272	470
480	26.272	26.328	26.383	26.439	26.495	26.551	26.606	26.662	26.718	26.774	26.829	480
490	26.829	26.885	26.941	26.997	27.053	27.109	27.165	27.220	27.276	27.332	27.388	490
500	27.388	27.444	27.500	27.556	27.612	27.668	27.724	27.780	27.836	27.893	27.949	500
510	27.949	28.005	28.061	28.117	28.173	28.230	28.286	28.342	28.398	28.455	28.511	510

Table 8.1.5 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
520	28.511	28.567	28.624	28.680	28.736	28.793	28.849	28.906	28.962	29.019	29.075	520
530	29.075	29.132	29.188	29.245	29.301	29.358	29.415	29.471	29.528	29.585	29.642	530
540	29.642	29.698	29.755	29.812	29.869	29.926	29.983	30.039	30.096	30.153	30.210	540
550	30.210	30.267	30.324	30.381	30.439	30.496	30.553	30.610	30.667	30.724	30.782	550
560	30.782	30.839	30.896	30.954	31.011	31.068	31.126	31.183	31.241	31.298	31.356	560
570	31.356	31.413	31.471	31.528	31.586	31.644	31.702	31.759	31.817	31.875	31.933	570
580	31.933	31.991	32.048	32.106	32.164	32.222	32.280	32.338	32.396	32.455	32.513	580
590	32.513	32.571	32.629	32.687	32.746	32.804	32.862	32.921	32.979	33.038	33.096	590
600	33.096	33.155	33.213	33.272	33.330	33.389	33.448	33.506	33.565	33.624	33.683	600
610	33.683	33.742	33.800	33.859	33.918	33.977	34.036	34.095	34.155	34.214	34.273	610
620	34.273	34.332	34.391	34.451	34.510	34.569	34.629	34.688	34.748	34.807	34.867	620
630	34.867	34.926	34.986	35.046	35.105	35.165	35.225	35.285	35.344	35.404	35.464	630
640	35.464	35.524	35.584	35.644	35.704	35.764	35.825	35.885	35.945	36.005	36.066	640
650	36.066	36.126	36.186	36.247	36.307	36.368	36.428	36.489	36.549	36.610	36.671	650
660	36.671	36.732	36.792	36.853	36.914	36.975	37.036	37.097	37.158	37.219	37.280	660
670	37.280	37.341	37.402	37.463	37.525	37.586	37.647	37.709	37.770	37.831	37.893	670
680	37.893	37.954	38.016	38.078	38.139	38.201	38.262	38.324	38.386	38.448	38.510	680
690	38.510	38.572	38.633	38.695	38.757	38.819	38.882	38.944	39.006	39.068	39.130	690
700	39.130	39.192	39.255	39.317	39.379	39.442	39.504	39.567	39.629	39.692	39.754	700
710	39.754	39.817	39.880	39.942	40.005	40.068	40.131	40.193	40.256	40.319	40.382	710
720	40.382	40.445	40.508	40.571	40.634	40.697	40.760	40.823	40.886	40.950	41.013	720
730	41.013	41.076	41.139	41.203	41.266	41.329	41.393	41.456	41.520	41.583	41.647	730
740	41.647	41.710	41.774	41.837	41.901	41.965	42.028	42.092	42.156	42.219	42.283	740
750	42.283	42.347	42.411	42.475	42.538	42.602	42.666	42.730	42.794	42.858	42.922	750

T/C Type J - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.6 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-350					-8.096	-8.085	-8.074	-8.063	-8.052	-8.041	-8.030	-350
-340	-8.030	-8.019	-8.008	-7.996	-7.985	-7.973	-7.962	-7.950	-7.938	-7.927	-7.915	-340
-330	-7.915	-7.903	-7.890	-7.878	-7.866	-7.854	-7.841	-7.829	-7.816	-7.803	-7.791	-330
-320	-7.791	-7.778	-7.765	-7.752	-7.739	-7.726	-7.712	-7.699	-7.686	-7.672	-7.659	-320
-310	-7.659	-7.645	-7.631	-7.618	-7.604	-7.590	-7.576	-7.562	-7.548	-7.533	-7.519	-310
-300	-7.519	-7.505	-7.490	-7.476	-7.461	-7.447	-7.432	-7.417	-7.402	-7.387	-7.372	-300
-290	-7.372	-7.357	-7.342	-7.327	-7.311	-7.296	-7.281	-7.265	-7.250	-7.234	-7.218	-290
-280	-7.218	-7.202	-7.187	-7.171	-7.155	-7.139	-7.122	-7.106	-7.090	-7.074	-7.057	-280
-270	-7.057	-7.041	-7.024	-7.008	-6.991	-6.974	-6.958	-6.941	-6.924	-6.907	-6.890	-270
-260	-6.890	-6.873	-6.856	-6.838	-6.821	-6.804	-6.786	-6.769	-6.751	-6.734	-6.716	-260
-250	-6.716	-6.698	-6.680	-6.663	-6.645	-6.627	-6.609	-6.591	-6.572	-6.554	-6.536	-250
-240	-6.536	-6.518	-6.499	-6.481	-6.462	-6.444	-6.425	-6.407	-6.388	-6.369	-6.350	-240
-230	-6.350	-6.331	-6.312	-6.293	-6.274	-6.255	-6.236	-6.217	-6.198	-6.178	-6.159	-230
-220	-6.159	-6.139	-6.120	-6.100	-6.081	-6.061	-6.041	-6.022	-6.002	-5.982	-5.962	-220
-210	-5.962	-5.942	-5.922	-5.902	-5.882	-5.861	-5.841	-5.821	-5.801	-5.780	-5.760	-210
-200	-5.760	-5.739	-5.719	-5.698	-5.678	-5.657	-5.636	-5.615	-5.594	-5.574	-5.553	-200
-190	-5.553	-5.532	-5.511	-5.490	-5.468	-5.447	-5.426	-5.405	-5.383	-5.362	-5.341	-190
-180	-5.341	-5.319	-5.298	-5.276	-5.255	-5.233	-5.211	-5.190	-5.168	-5.146	-5.124	-180
-170	-5.124	-5.102	-5.080	-5.058	-5.036	-5.014	-4.992	-4.970	-4.948	-4.925	-4.903	-170
-160	-4.903	-4.881	-4.858	-4.836	-4.813	-4.791	-4.768	-4.746	-4.723	-4.700	-4.678	-160

Table 8.1.6 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-150	-4.678	-4.655	-4.632	-4.609	-4.586	-4.563	-4.540	-4.517	-4.494	-4.471	-4.448	-150
-140	-4.448	-4.425	-4.402	-4.379	-4.355	-4.332	-4.309	-4.285	-4.262	-4.238	-4.215	-140
-130	-4.215	-4.191	-4.168	-4.144	-4.120	-4.097	-4.073	-4.049	-4.025	-4.001	-3.978	-130
-120	-3.978	-3.954	-3.930	-3.906	-3.882	-3.858	-3.833	-3.809	-3.785	-3.761	-3.737	-120
-110	-3.737	-3.712	-3.688	-3.664	-3.639	-3.615	-3.590	-3.566	-3.541	-3.517	-3.492	-110
-100	-3.492	-3.468	-3.443	-3.418	-3.394	-3.369	-3.344	-3.319	-3.294	-3.270	-3.245	-100
-90	-3.245	-3.220	-3.195	-3.170	-3.145	-3.120	-3.094	-3.069	-3.044	-3.019	-2.994	-90
-80	-2.994	-2.968	-2.943	-2.918	-2.892	-2.867	-2.842	-2.816	-2.791	-2.765	-2.740	-80
-70	-2.740	-2.714	-2.689	-2.663	-2.637	-2.612	-2.586	-2.560	-2.534	-2.509	-2.483	-70
-60	-2.483	-2.457	-2.431	-2.405	-2.379	-2.353	-2.327	-2.301	-2.275	-2.249	-2.223	-60
-50	-2.223	-2.197	-2.171	-2.144	-2.118	-2.092	-2.066	-2.039	-2.013	-1.987	-1.960	-50
-40	-1.960	-1.934	-1.908	-1.881	-1.855	-1.828	-1.802	-1.775	-1.748	-1.722	-1.695	-40
-30	-1.695	-1.669	-1.642	-1.615	-1.589	-1.562	-1.535	-1.508	-1.481	-1.455	-1.428	-30
-20	-1.428	-1.401	-1.374	-1.347	-1.320	-1.293	-1.266	-1.239	-1.212	-1.185	-1.158	-20
-10	-1.158	-1.131	-1.103	-1.076	-1.049	-1.022	-0.995	-0.967	-0.940	-0.913	-0.885	-10
0	-0.885	-0.858	-0.831	-0.803	-0.776	-0.748	-0.721	-0.694	-0.666	-0.639	-0.611	0
10	-0.611	-0.583	-0.556	-0.528	-0.501	-0.473	-0.445	-0.418	-0.390	-0.362	-0.334	10
20	-0.334	-0.307	-0.279	-0.251	-0.223	-0.195	-0.168	-0.140	-0.112	-0.084	-0.056	20
30	-0.056	-0.028	0.000	0.028	0.056	0.084	0.112	0.140	0.168	0.196	0.224	30
40	0.224	0.253	0.281	0.309	0.337	0.365	0.394	0.422	0.450	0.478	0.507	40
50	0.507	0.535	0.563	0.592	0.620	0.648	0.677	0.705	0.734	0.762	0.791	50
60	0.791	0.819	0.848	0.876	0.905	0.933	0.962	0.990	1.019	1.048	1.076	60
70	1.076	1.105	1.134	1.162	1.191	1.220	1.248	1.277	1.306	1.335	1.363	70
80	1.363	1.392	1.421	1.450	1.479	1.507	1.536	1.565	1.594	1.623	1.652	80
90	1.652	1.681	1.710	1.739	1.768	1.797	1.826	1.855	1.884	1.913	1.942	90
100	1.942	1.971	2.000	2.029	2.058	2.088	2.117	2.146	2.175	2.204	2.233	100
110	2.233	2.263	2.292	2.321	2.350	2.380	2.409	2.438	2.467	2.497	2.526	110
120	2.526	2.555	2.585	2.614	2.644	2.673	2.702	2.732	2.761	2.791	2.820	120
130	2.820	2.849	2.879	2.908	2.938	2.967	2.997	3.026	3.056	3.085	3.115	130
140	3.115	3.145	3.174	3.204	3.233	3.263	3.293	3.322	3.352	3.381	3.411	140
150	3.411	3.441	3.470	3.500	3.530	3.560	3.589	3.619	3.649	3.678	3.708	150
160	3.708	3.738	3.768	3.798	3.827	3.857	3.887	3.917	3.947	3.976	4.006	160
170	4.006	4.036	4.066	4.096	4.126	4.156	4.186	4.216	4.245	4.275	4.305	170
180	4.305	4.335	4.365	4.395	4.425	4.455	4.485	4.515	4.545	4.575	4.605	180
190	4.605	4.635	4.665	4.695	4.725	4.755	4.786	4.816	4.846	4.876	4.906	190
200	4.906	4.936	4.966	4.996	5.026	5.057	5.087	5.117	5.147	5.177	5.207	200
210	5.207	5.238	5.268	5.298	5.328	5.358	5.389	5.419	5.449	5.479	5.509	210
220	5.509	5.540	5.570	5.600	5.630	5.661	5.691	5.721	5.752	5.782	5.812	220
230	5.812	5.843	5.873	5.903	5.934	5.964	5.994	6.025	6.055	6.085	6.116	230
240	6.116	6.146	6.176	6.207	6.237	6.268	6.298	6.328	6.359	6.389	6.420	240
250	6.420	6.450	6.481	6.511	6.541	6.572	6.602	6.633	6.663	6.694	6.724	250
260	6.724	6.755	6.785	6.816	6.846	6.877	6.907	6.938	6.968	6.999	7.029	260
270	7.029	7.060	7.090	7.121	7.151	7.182	7.212	7.243	7.274	7.304	7.335	270
280	7.335	7.365	7.396	7.426	7.457	7.488	7.518	7.549	7.579	7.610	7.641	280
290	7.641	7.671	7.702	7.732	7.763	7.794	7.824	7.855	7.885	7.916	7.947	290
300	7.947	7.977	8.008	8.039	8.069	8.100	8.131	8.161	8.192	8.223	8.253	300
310	8.253	8.284	8.315	8.345	8.376	8.407	8.437	8.468	8.499	8.530	8.560	310
320	8.560	8.591	8.622	8.652	8.683	8.714	8.745	8.775	8.806	8.837	8.867	320
330	8.867	8.898	8.929	8.960	8.990	9.021	9.052	9.083	9.113	9.144	9.175	330
340	9.175	9.206	9.236	9.267	9.298	9.329	9.359	9.390	9.421	9.452	9.483	340
350	9.483	9.513	9.544	9.575	9.606	9.636	9.667	9.698	9.729	9.760	9.790	350
360	9.790	9.821	9.852	9.883	9.914	9.944	9.975	10.006	10.037	10.068	10.098	360
370	10.098	10.129	10.160	10.191	10.222	10.252	10.283	10.314	10.345	10.376	10.407	370

Table 8.1.6 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
380	10.407	10.437	10.468	10.499	10.530	10.561	10.592	10.622	10.653	10.684	10.715	380
390	10.715	10.746	10.777	10.807	10.838	10.869	10.900	10.931	10.962	10.992	11.023	390
400	11.023	11.054	11.085	11.116	11.147	11.177	11.208	11.239	11.270	11.301	11.332	400
410	11.332	11.363	11.393	11.424	11.455	11.486	11.517	11.548	11.578	11.609	11.640	410
420	11.640	11.671	11.702	11.733	11.764	11.794	11.825	11.856	11.887	11.918	11.949	420
430	11.949	11.980	12.010	12.041	12.072	12.103	12.134	12.165	12.196	12.226	12.257	430
440	12.257	12.288	12.319	12.350	12.381	12.411	12.442	12.473	12.504	12.535	12.566	440
450	12.566	12.597	12.627	12.658	12.689	12.720	12.751	12.782	12.813	12.843	12.874	450
460	12.874	12.905	12.936	12.967	12.998	13.029	13.059	13.090	13.121	13.152	13.183	460
470	13.183	13.214	13.244	13.275	13.306	13.337	13.368	13.399	13.430	13.460	13.491	470
480	13.491	13.522	13.553	13.584	13.615	13.645	13.676	13.707	13.738	13.769	13.800	480
490	13.800	13.830	13.861	13.892	13.923	13.954	13.985	14.015	14.046	14.077	14.108	490
500	14.108	14.139	14.170	14.200	14.231	14.262	14.293	14.324	14.355	14.385	14.416	500
510	14.416	14.447	14.478	14.509	14.539	14.570	14.601	14.632	14.663	14.694	14.724	510
520	14.724	14.755	14.786	14.817	14.848	14.878	14.909	14.940	14.971	15.002	15.032	520
530	15.032	15.063	15.094	15.125	15.156	15.186	15.217	15.248	15.279	15.310	15.340	530
540	15.340	15.371	15.402	15.433	15.464	15.494	15.525	15.556	15.587	15.617	15.648	540
550	15.648	15.679	15.710	15.741	15.771	15.802	15.833	15.864	15.894	15.925	15.956	550
560	15.956	15.987	16.018	16.048	16.079	16.110	16.141	16.171	16.202	16.233	16.264	560
570	16.264	16.294	16.325	16.356	16.387	16.417	16.448	16.479	16.510	16.540	16.571	570
580	16.571	16.602	16.633	16.663	16.694	16.725	16.756	16.786	16.817	16.848	16.879	580
590	16.879	16.909	16.940	16.971	17.001	17.032	17.063	17.094	17.124	17.155	17.186	590
600	17.186	17.217	17.247	17.278	17.309	17.339	17.370	17.401	17.432	17.462	17.493	600
610	17.493	17.524	17.554	17.585	17.616	17.646	17.677	17.708	17.739	17.769	17.800	610
620	17.800	17.831	17.861	17.892	17.923	17.953	17.984	18.015	18.046	18.076	18.107	620
630	18.107	18.138	18.168	18.199	18.230	18.260	18.291	18.322	18.352	18.383	18.414	630
640	18.414	18.444	18.475	18.506	18.537	18.567	18.598	18.629	18.659	18.690	18.721	640
650	18.721	18.751	18.782	18.813	18.843	18.874	18.905	18.935	18.966	18.997	19.027	650
660	19.027	19.058	19.089	19.119	19.150	19.180	19.211	19.242	19.272	19.303	19.334	660
670	19.334	19.364	19.395	19.426	19.456	19.487	19.518	19.548	19.579	19.610	19.640	670
680	19.640	19.671	19.702	19.732	19.763	19.793	19.824	19.855	19.885	19.916	19.947	680
690	19.947	19.977	20.008	20.039	20.069	20.100	20.131	20.161	20.192	20.222	20.253	690
700	20.253	20.284	20.314	20.345	20.376	20.406	20.437	20.467	20.498	20.529	20.559	700
710	20.559	20.590	20.621	20.651	20.682	20.713	20.743	20.774	20.804	20.835	20.866	710
720	20.866	20.896	20.927	20.958	20.988	21.019	21.049	21.080	21.111	21.141	21.172	720
730	21.172	21.203	21.233	21.264	21.295	21.325	21.356	21.386	21.417	21.448	21.478	730
740	21.478	21.509	21.540	21.570	21.601	21.631	21.662	21.693	21.723	21.754	21.785	740
750	21.785	21.815	21.846	21.877	21.907	21.938	21.968	21.999	22.030	22.060	22.091	750
760	22.091	22.122	22.152	22.183	22.214	22.244	22.275	22.305	22.336	22.367	22.397	760
770	22.397	22.428	22.459	22.489	22.520	22.551	22.581	22.612	22.643	22.673	22.704	770
780	22.704	22.735	22.765	22.796	22.826	22.857	22.888	22.918	22.949	22.980	23.010	780
790	23.010	23.041	23.072	23.102	23.133	23.164	23.194	23.225	23.256	23.286	23.317	790
800	23.317	23.348	23.378	23.409	23.440	23.471	23.501	23.532	23.563	23.593	23.624	800
810	23.624	23.655	23.685	23.716	23.747	23.777	23.808	23.839	23.870	23.900	23.931	810
820	23.931	23.962	23.992	24.023	24.054	24.085	24.115	24.146	24.177	24.207	24.238	820
830	24.238	24.269	24.300	24.330	24.361	24.392	24.423	24.453	24.484	24.515	24.546	830
840	24.546	24.576	24.607	24.638	24.669	24.699	24.730	24.761	24.792	24.822	24.853	840
850	24.853	24.884	24.915	24.946	24.976	25.007	25.038	25.069	25.099	25.130	25.161	850
860	25.161	25.192	25.223	25.254	25.284	25.315	25.346	25.377	25.408	25.438	25.469	860
870	25.469	25.500	25.531	25.562	25.593	25.623	25.654	25.685	25.716	25.747	25.778	870
880	25.778	25.809	25.840	25.870	25.901	25.932	25.963	25.994	26.025	26.056	26.087	880
890	26.087	26.118	26.148	26.179	26.210	26.241	26.272	26.303	26.334	26.365	26.396	890
900	26.396	26.427	26.458	26.489	26.520	26.551	26.582	26.613	26.644	26.675	26.705	900

Table 8.1.6 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
910	26.705	26.736	26.767	26.798	26.829	26.860	26.891	26.922	26.954	26.985	27.016	910
920	27.016	27.047	27.078	27.109	27.140	27.171	27.202	27.233	27.264	27.295	27.326	920
930	27.326	27.357	27.388	27.419	27.450	27.482	27.513	27.544	27.575	27.606	27.637	930
940	27.637	27.668	27.699	27.731	27.762	27.793	27.824	27.855	27.886	27.917	27.949	940
950	27.949	27.980	28.011	28.042	28.073	28.105	28.136	28.167	28.198	28.230	28.261	950
960	28.261	28.292	28.323	28.355	28.386	28.417	28.448	28.480	28.511	28.542	28.573	960
970	28.573	28.605	28.636	28.667	28.699	28.730	28.761	28.793	28.824	28.855	28.887	970
980	28.887	28.918	28.950	28.981	29.012	29.044	29.075	29.107	29.138	29.169	29.201	980
990	29.201	29.232	29.264	29.295	29.327	29.358	29.390	29.421	29.452	29.484	29.515	990
1000	29.515	29.547	29.578	29.610	29.642	29.673	29.705	29.736	29.768	29.799	29.831	1000
1010	29.831	29.862	29.894	29.926	29.957	29.989	30.020	30.052	30.084	30.115	30.147	1010
1020	30.147	30.179	30.210	30.242	30.274	30.305	30.337	30.369	30.400	30.432	30.464	1020
1030	30.464	30.496	30.527	30.559	30.591	30.623	30.654	30.686	30.718	30.750	30.782	1030
1040	30.782	30.813	30.845	30.877	30.909	30.941	30.973	31.005	31.036	31.068	31.100	1040
1050	31.100	31.132	31.164	31.196	31.228	31.260	31.292	31.324	31.356	31.388	31.420	1050
1060	31.420	31.452	31.484	31.516	31.548	31.580	31.612	31.644	31.676	31.708	31.740	1060
1070	31.740	31.772	31.804	31.836	31.868	31.901	31.933	31.965	31.997	32.029	32.061	1070
1080	32.061	32.094	32.126	32.158	32.190	32.222	32.255	32.287	32.319	32.351	32.384	1080
1090	32.384	32.416	32.448	32.480	32.513	32.545	32.577	32.610	32.642	32.674	32.707	1090
1100	32.707	32.739	32.772	32.804	32.836	32.869	32.901	32.934	32.966	32.999	33.031	1100
1110	33.031	33.064	33.096	33.129	33.161	33.194	33.226	33.259	33.291	33.324	33.356	1110
1120	33.356	33.389	33.422	33.454	33.487	33.519	33.552	33.585	33.617	33.650	33.683	1120
1130	33.683	33.715	33.748	33.781	33.814	33.846	33.879	33.912	33.945	33.977	34.010	1130
1140	34.010	34.043	34.076	34.109	34.141	34.174	34.207	34.240	34.273	34.306	34.339	1140
1150	34.339	34.372	34.405	34.437	34.470	34.503	34.536	34.569	34.602	34.635	34.668	1150
1160	34.668	34.701	34.734	34.767	34.801	34.834	34.867	34.900	34.933	34.966	34.999	1160
1170	34.999	35.032	35.065	35.099	35.132	35.165	35.198	35.231	35.265	35.298	35.331	1170
1180	35.331	35.364	35.398	35.431	35.464	35.498	35.531	35.564	35.598	35.631	35.664	1180
1190	35.664	35.698	35.731	35.764	35.798	35.831	35.865	35.898	35.932	35.965	35.999	1190
1200	35.999	36.032	36.066	36.099	36.133	36.166	36.200	36.233	36.267	36.301	36.334	1200
1210	36.334	36.368	36.401	36.435	36.469	36.502	36.536	36.570	36.603	36.637	36.671	1210
1220	36.671	36.705	36.738	36.772	36.806	36.840	36.873	36.907	36.941	36.975	37.009	1220
1230	37.009	37.043	37.076	37.110	37.144	37.178	37.212	37.246	37.280	37.314	37.348	1230
1240	37.348	37.382	37.416	37.450	37.484	37.518	37.552	37.586	37.620	37.654	37.688	1240
1250	37.688	37.722	37.756	37.790	37.825	37.859	37.893	37.927	37.961	37.995	38.030	1250
1260	38.030	38.064	38.098	38.132	38.167	38.201	38.235	38.269	38.304	38.338	38.372	1260
1270	38.372	38.407	38.441	38.475	38.510	38.544	38.578	38.613	38.647	38.682	38.716	1270
1280	38.716	38.751	38.785	38.819	38.854	38.888	38.923	38.957	38.992	39.027	39.061	1280
1290	39.061	39.096	39.130	39.165	39.199	39.234	39.269	39.303	39.338	39.373	39.407	1290
1300	39.407	39.442	39.477	39.511	39.546	39.581	39.615	39.650	39.685	39.720	39.754	1300
1310	39.754	39.789	39.824	39.859	39.894	39.928	39.963	39.998	40.033	40.068	40.103	1310
1320	40.103	40.138	40.172	40.207	40.242	40.277	40.312	40.347	40.382	40.417	40.452	1320
1330	40.452	40.487	40.522	40.557	40.592	40.627	40.662	40.697	40.732	40.767	40.802	1330
1340	40.802	40.837	40.872	40.908	40.943	40.978	41.013	41.048	41.083	41.118	41.154	1340
1350	41.154	41.189	41.224	41.259	41.294	41.329	41.365	41.400	41.435	41.470	41.506	1350
1360	41.506	41.541	41.576	41.611	41.647	41.682	41.717	41.753	41.788	41.823	41.859	1360
1370	41.859	41.894	41.929	41.965	42.000	42.035	42.071	42.106	42.142	42.177	42.212	1370
1380	42.212	42.248	42.283	42.319	42.354	42.390	42.425	42.460	42.496	42.531	42.567	1380
1390	42.567	42.602	42.638	42.673	42.709	42.744	42.780	42.815	42.851	42.886	42.922	1390

T/C Type K - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.7 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-270	-6.458	-6.457	-6.456	-6.455	-6.453	-6.452	-6.450	-6.448	-6.446	-6.444	-6.441	-270
-260	-6.441	-6.438	-6.435	-6.432	-6.429	-6.425	-6.421	-6.417	-6.413	-6.408	-6.404	-260
-250	-6.404	-6.399	-6.394	-6.388	-6.382	-6.377	-6.371	-6.364	-6.358	-6.351	-6.344	-250
-240	-6.344	-6.337	-6.329	-6.322	-6.314	-6.306	-6.297	-6.289	-6.280	-6.271	-6.262	-240
-230	-6.262	-6.253	-6.243	-6.233	-6.223	-6.213	-6.202	-6.192	-6.181	-6.170	-6.158	-230
-220	-6.158	-6.147	-6.135	-6.123	-6.111	-6.099	-6.087	-6.074	-6.061	-6.048	-6.035	-220
-210	-6.035	-6.021	-6.007	-5.994	-5.980	-5.965	-5.951	-5.936	-5.922	-5.907	-5.891	-210
-200	-5.891	-5.876	-5.860	-5.845	-5.829	-5.813	-5.796	-5.780	-5.763	-5.747	-5.730	-200
-190	-5.730	-5.712	-5.695	-5.678	-5.660	-5.642	-5.624	-5.606	-5.587	-5.569	-5.550	-190
-180	-5.550	-5.531	-5.512	-5.493	-5.474	-5.454	-5.434	-5.414	-5.394	-5.374	-5.354	-180
-170	-5.354	-5.333	-5.313	-5.292	-5.271	-5.249	-5.228	-5.207	-5.185	-5.163	-5.141	-170
-160	-5.141	-5.119	-5.097	-5.074	-5.051	-5.029	-5.006	-4.983	-4.959	-4.936	-4.912	-160
-150	-4.912	-4.889	-4.865	-4.841	-4.817	-4.792	-4.768	-4.743	-4.719	-4.694	-4.669	-150
-140	-4.669	-4.644	-4.618	-4.593	-4.567	-4.541	-4.515	-4.489	-4.463	-4.437	-4.410	-140
-130	-4.410	-4.384	-4.357	-4.330	-4.303	-4.276	-4.248	-4.221	-4.193	-4.166	-4.138	-130
-120	-4.138	-4.110	-4.082	-4.053	-4.025	-3.997	-3.968	-3.939	-3.910	-3.881	-3.852	-120
-110	-3.852	-3.823	-3.793	-3.764	-3.734	-3.704	-3.674	-3.644	-3.614	-3.584	-3.553	-110
-100	-3.553	-3.523	-3.492	-3.461	-3.430	-3.399	-3.368	-3.337	-3.305	-3.274	-3.242	-100
-90	-3.242	-3.211	-3.179	-3.147	-3.115	-3.082	-3.050	-3.018	-2.985	-2.953	-2.920	-90
-80	-2.920	-2.887	-2.854	-2.821	-2.788	-2.754	-2.721	-2.687	-2.654	-2.620	-2.586	-80
-70	-2.586	-2.552	-2.518	-2.484	-2.450	-2.416	-2.381	-2.347	-2.312	-2.277	-2.243	-70
-60	-2.243	-2.208	-2.173	-2.137	-2.102	-2.067	-2.032	-1.996	-1.961	-1.925	-1.889	-60
-50	-1.889	-1.853	-1.817	-1.781	-1.745	-1.709	-1.673	-1.636	-1.600	-1.563	-1.527	-50
-40	-1.527	-1.490	-1.453	-1.416	-1.379	-1.342	-1.305	-1.268	-1.231	-1.193	-1.156	-40
-30	-1.156	-1.118	-1.081	-1.043	-1.005	-0.968	-0.930	-0.892	-0.854	-0.816	-0.777	-30
-20	-0.777	-0.739	-0.701	-0.662	-0.624	-0.585	-0.547	-0.508	-0.469	-0.431	-0.392	-20
-10	-0.392	-0.353	-0.314	-0.275	-0.236	-0.197	-0.157	-0.118	-0.079	-0.039	0.000	-10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.162	1.203	20
30	1.203	1.244	1.285	1.325	1.366	1.407	1.448	1.489	1.529	1.570	1.611	30
40	1.611	1.652	1.693	1.734	1.776	1.817	1.858	1.899	1.940	1.981	2.022	40
50	2.022	2.064	2.105	2.146	2.188	2.229	2.270	2.312	2.353	2.394	2.436	50
60	2.436	2.477	2.519	2.560	2.601	2.643	2.684	2.726	2.767	2.809	2.850	60
70	2.850	2.892	2.933	2.975	3.016	3.058	3.100	3.141	3.183	3.224	3.266	70
80	3.266	3.307	3.349	3.390	3.432	3.473	3.515	3.556	3.598	3.639	3.681	80
90	3.681	3.722	3.764	3.805	3.847	3.888	3.930	3.971	4.012	4.054	4.095	90
100	4.095	4.137	4.178	4.219	4.261	4.302	4.343	4.384	4.426	4.467	4.508	100
110	4.508	4.549	4.590	4.632	4.673	4.714	4.755	4.796	4.837	4.878	4.919	110
120	4.919	4.960	5.001	5.042	5.083	5.124	5.164	5.205	5.246	5.287	5.327	120
130	5.327	5.368	5.409	5.450	5.490	5.531	5.571	5.612	5.652	5.693	5.733	130
140	5.733	5.774	5.814	5.855	5.895	5.936	5.976	6.016	6.057	6.097	6.137	140
150	6.137	6.177	6.218	6.258	6.298	6.338	6.378	6.419	6.459	6.499	6.539	150
160	6.539	6.579	6.619	6.659	6.699	6.739	6.779	6.819	6.859	6.899	6.939	160
170	6.939	6.979	7.019	7.059	7.099	7.139	7.179	7.219	7.259	7.299	7.338	170
180	7.338	7.378	7.418	7.458	7.498	7.538	7.578	7.618	7.658	7.697	7.737	180
190	7.737	7.777	7.817	7.857	7.897	7.937	7.977	8.017	8.057	8.097	8.137	190

Table 8.1.7 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
200	8.137	8.177	8.216	8.256	8.296	8.336	8.376	8.416	8.456	8.497	8.537	200
210	8.537	8.577	8.617	8.657	8.697	8.737	8.777	8.817	8.857	8.898	8.938	210
220	8.938	8.978	9.018	9.058	9.099	9.139	9.179	9.220	9.260	9.300	9.341	220
230	9.341	9.381	9.421	9.462	9.502	9.543	9.583	9.624	9.664	9.705	9.745	230
240	9.745	9.786	9.826	9.867	9.907	9.948	9.989	10.029	10.070	10.111	10.151	240
250	10.151	10.192	10.233	10.274	10.315	10.355	10.396	10.437	10.478	10.519	10.560	250
260	10.560	10.600	10.641	10.682	10.723	10.764	10.805	10.846	10.887	10.928	10.969	260
270	10.969	11.010	11.051	11.093	11.134	11.175	11.216	11.257	11.298	11.339	11.381	270
280	11.381	11.422	11.463	11.504	11.546	11.587	11.628	11.669	11.711	11.752	11.793	280
290	11.793	11.835	11.876	11.918	11.959	12.000	12.042	12.083	12.125	12.166	12.207	290
300	12.207	12.249	12.290	12.332	12.373	12.415	12.456	12.498	12.539	12.581	12.623	300
310	12.623	12.664	12.706	12.747	12.789	12.831	12.872	12.914	12.955	12.997	13.039	310
320	13.039	13.080	13.122	13.164	13.205	13.247	13.289	13.331	13.372	13.414	13.456	320
330	13.456	13.497	13.539	13.581	13.623	13.665	13.706	13.748	13.790	13.832	13.874	330
340	13.874	13.915	13.957	13.999	14.041	14.083	14.125	14.167	14.208	14.250	14.292	340
350	14.292	14.334	14.376	14.418	14.460	14.502	14.544	14.586	14.628	14.670	14.712	350
360	14.712	14.754	14.796	14.838	14.880	14.922	14.964	15.006	15.048	15.090	15.132	360
370	15.132	15.174	15.216	15.258	15.300	15.342	15.384	15.426	15.468	15.510	15.552	370
380	15.552	15.594	15.636	15.679	15.721	15.763	15.805	15.847	15.889	15.931	15.974	380
390	15.974	16.016	16.058	16.100	16.142	16.184	16.227	16.269	16.311	16.353	16.395	390
400	16.395	16.438	16.480	16.522	16.564	16.607	16.649	16.691	16.733	16.776	16.818	400
410	16.818	16.860	16.902	16.945	16.987	17.029	17.072	17.114	17.156	17.199	17.241	410
420	17.241	17.283	17.326	17.368	17.410	17.453	17.495	17.537	17.580	17.622	17.664	420
430	17.664	17.707	17.749	17.792	17.834	17.876	17.919	17.964	18.004	18.046	18.088	430
440	18.088	18.131	18.173	18.216	18.258	18.301	18.343	18.385	18.428	18.470	18.513	440
450	18.513	18.555	18.598	18.640	18.683	18.725	18.768	18.810	18.853	18.895	18.938	450
460	18.938	18.980	19.023	19.065	19.108	19.150	19.193	19.235	19.278	19.320	19.363	460
470	19.363	19.405	19.448	19.490	19.533	19.576	19.618	19.661	19.703	19.746	19.788	470
480	19.788	19.831	19.873	19.916	19.959	20.001	20.044	20.086	20.129	20.172	20.214	480
490	20.214	20.257	20.299	20.342	20.385	20.427	20.470	20.512	20.555	20.98	20.640	490
500	20.640	20.683	20.725	20.768	20.811	20.853	20.896	20.938	20.981	21.024	21.066	500
510	21.066	21.109	21.152	21.194	21.237	21.280	21.322	21.365	21.407	21.450	21.493	510
520	21.493	21.535	21.578	21.621	21.663	21.706	21.749	21.791	21.834	21.876	21.919	520
530	21.919	21.962	22.004	22.047	22.090	22.132	22.175	22.218	22.260	22.303	22.346	530
540	22.346	22.388	22.431	22.473	22.516	22.559	22.601	22.644	22.687	22.729	22.772	540
550	22.772	22.815	22.857	22.900	22.942	22.985	23.028	23.070	23.113	23.156	23.198	550
560	23.198	23.241	23.284	23.326	23.369	23.411	23.454	23.497	23.539	23.582	23.624	560
570	23.624	23.667	23.710	23.752	23.795	23.837	23.880	23.923	23.965	24.008	24.050	570
580	24.050	24.093	24.136	24.178	24.221	24.263	24.306	24.348	24.391	24.434	24.476	580
590	24.476	24.519	24.561	24.604	24.646	24.689	24.731	24.774	24.817	24.859	24.902	590
600	24.902	24.944	24.987	25.029	25.072	25.114	25.157	25.199	25.242	25.284	25.327	600
610	25.327	25.369	25.412	25.454	25.497	25.539	25.582	25.624	25.666	25.709	25.751	610
620	25.751	25.794	25.836	25.879	25.921	25.964	26.006	26.048	26.091	26.133	26.176	620
630	26.176	26.218	26.260	26.303	26.345	26.387	26.430	26.472	26.515	26.557	26.599	630
640	26.599	26.642	26.684	26.726	26.769	26.811	26.853	26.896	26.938	26.980	27.022	640
650	27.022	27.065	27.107	27.149	27.192	27.234	27.276	27.318	27.361	27.403	27.445	650
660	27.445	27.487	27.529	27.572	27.614	27.656	27.698	27.740	27.783	27.825	27.867	660
670	27.867	27.909	27.951	27.993	28.035	28.078	28.120	28.162	28.204	28.246	28.288	670
680	28.288	28.330	28.372	28.414	28.456	28.498	28.540	28.583	28.625	28.667	28.709	680
690	28.709	28.751	28.793	28.835	28.877	28.919	28.961	29.002	29.044	29.086	29.128	690
700	29.128	29.170	29.212	29.254	29.296	29.338	29.380	29.422	29.464	29.505	29.547	700
710	29.547	29.589	29.631	29.673	29.715	29.756	29.798	29.840	29.882	29.924	29.965	710
720	29.965	30.007	30.049	30.091	30.132	30.174	30.216	30.257	30.299	30.341	30.383	720

Table 8.1.7 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
730	30.383	30.424	30.466	30.508	30.549	30.591	30.632	30.674	30.716	30.757	30.799	730
740	30.799	30.840	30.882	30.924	30.965	31.007	31.048	31.090	31.131	31.173	31.214	740
750	31.214	31.256	31.297	31.339	31.380	31.422	31.463	31.504	31.546	31.587	31.629	750
760	31.629	31.670	31.712	31.753	31.794	31.836	31.877	31.918	31.960	32.001	32.042	760
770	32.042	32.084	32.125	32.166	32.207	32.249	32.290	32.331	32.372	32.414	32.455	770
780	32.455	32.496	32.537	32.578	32.619	32.661	32.702	32.743	32.784	32.825	32.866	780
790	32.866	32.907	32.948	32.990	33.031	33.072	33.113	33.154	33.195	33.236	33.277	790
800	33.277	33.318	33.359	33.400	33.441	33.482	33.523	33.564	33.604	33.645	33.686	800
810	33.686	33.727	33.768	33.809	33.850	33.891	33.931	33.972	34.013	34.054	34.095	810
820	34.095	34.136	34.176	34.217	34.258	34.299	34.339	34.380	34.421	34.461	34.502	820
830	34.502	34.543	34.583	34.624	34.665	34.705	34.746	34.787	34.827	34.868	34.909	830
840	34.909	34.949	34.990	35.030	35.071	35.111	35.152	35.192	35.233	35.273	35.314	840
850	35.314	35.354	35.395	35.435	35.476	35.516	35.557	35.597	35.637	35.678	35.718	850
860	35.718	35.758	35.799	35.839	35.880	35.920	35.960	36.000	36.041	36.081	36.121	860
870	36.121	36.162	36.202	36.242	36.282	36.323	36.363	36.403	36.443	36.483	36.524	870
880	36.524	36.564	36.604	36.644	36.684	36.724	36.764	36.804	36.844	36.885	36.925	880
890	36.925	36.965	37.005	37.045	37.085	37.125	37.165	37.205	37.245	37.285	37.325	890
900	37.325	37.365	37.405	37.445	37.484	37.524	37.564	37.604	37.644	37.684	37.724	900
910	37.724	37.764	37.803	37.843	37.883	37.923	37.963	38.002	38.042	38.082	38.122	910
920	38.122	38.162	38.201	38.241	38.281	38.320	38.360	38.400	38.439	38.479	38.519	920
930	38.519	38.558	38.598	38.638	38.677	38.717	38.756	38.796	38.836	38.875	38.915	930
940	38.915	38.954	38.994	39.033	39.073	39.112	39.152	39.191	39.231	39.270	39.310	940
950	39.310	39.349	39.388	39.428	39.467	39.507	39.546	39.585	39.625	39.664	39.703	950
960	39.703	39.743	39.782	39.821	39.861	39.900	39.939	39.979	40.018	40.057	40.096	960
970	40.096	40.136	40.175	40.214	40.253	40.292	40.332	40.371	40.410	40.449	40.488	970
980	40.488	40.527	40.566	40.605	40.645	40.684	40.723	40.762	40.801	40.840	40.879	980
990	40.879	40.918	40.957	40.996	41.035	41.074	41.113	41.152	41.191	41.230	41.269	990
1000	41.269	41.308	41.347	41.385	41.424	41.463	41.502	41.541	41.580	41.619	41.657	1000
1010	41.657	41.696	41.735	41.774	41.813	41.851	41.890	41.929	41.968	42.006	42.045	1010
1020	42.045	42.084	42.123	42.161	42.200	42.239	42.277	42.316	42.355	42.393	42.432	1020
1030	42.432	42.470	42.509	42.548	42.586	42.625	42.663	42.702	42.740	42.779	42.817	1030
1040	42.817	42.856	42.894	42.933	42.971	43.010	43.048	43.087	43.125	43.164	43.202	1040
1050	43.202	43.240	43.279	43.317	43.356	43.394	43.432	43.471	43.509	43.547	43.585	1050
1060	43.585	43.624	43.662	43.700	43.739	43.777	43.815	43.853	43.891	43.930	43.968	1060
1070	43.968	44.006	44.044	44.082	44.121	44.159	44.197	44.235	44.273	44.311	44.349	1070
1080	44.349	44.387	44.425	44.463	44.501	44.539	44.577	44.615	44.653	44.691	44.729	1080
1090	44.729	44.767	44.805	44.843	44.881	44.919	44.957	44.995	45.033	45.070	45.108	1090
1100	45.108	45.146	45.184	45.222	45.260	45.297	45.335	45.373	45.411	45.448	45.486	1100
1110	45.486	45.524	45.561	45.599	45.637	45.675	45.712	45.750	45.787	45.825	45.863	1110
1120	45.863	45.900	45.938	45.975	46.013	46.051	46.088	46.126	46.163	46.201	46.238	1120
1130	46.238	46.275	46.313	46.350	46.388	46.425	46.463	46.500	46.537	46.575	46.612	1130
1140	46.612	46.649	46.687	46.724	46.761	46.799	46.836	46.873	46.910	46.948	46.985	1140
1150	46.985	47.022	47.059	47.096	47.134	47.171	47.208	47.245	47.282	47.319	47.356	1150
1160	47.356	47.393	47.430	47.468	47.505	47.542	47.579	47.616	47.653	47.689	47.726	1160
1170	47.726	47.763	47.800	47.837	47.874	47.911	47.948	47.985	48.021	48.058	48.095	1170
1180	48.095	48.132	48.169	48.205	48.242	48.279	48.316	48.352	48.389	48.426	48.462	1180
1190	48.462	48.499	48.536	48.572	48.609	48.645	48.682	48.718	48.755	48.792	48.828	1190
1200	48.828	48.865	48.901	48.937	48.974	49.010	49.047	49.083	49.120	49.156	49.192	1200
1210	49.192	49.229	49.265	49.301	49.338	49.374	49.410	49.446	49.483	49.519	49.555	1210
1220	49.555	49.591	49.627	49.663	49.700	49.736	49.772	49.808	49.844	49.880	49.916	1220
1230	49.916	49.952	49.988	50.024	50.060	50.096	50.132	50.168	50.204	50.240	50.276	1230
1240	50.276	50.311	50.347	50.383	50.419	50.455	50.491	50.526	50.562	50.598	50.633	1240
1250	50.633	50.669	50.705	50.741	50.776	50.812	50.847	50.883	50.919	50.954	50.990	1250

Table 8.1.7 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1260	50.990	51.025	51.061	51.096	51.132	51.167	51.203	51.238	51.274	51.309	51.344	1260
1270	51.344	51.380	51.415	51.450	51.486	51.521	51.556	51.592	51.627	51.662	51.697	1270
1280	51.697	51.733	51.768	51.803	51.838	51.873	51.908	51.943	51.979	52.014	52.049	1280
1290	52.049	52.084	52.119	52.154	52.189	52.224	52.259	52.294	52.329	52.364	52.398	1290
1300	52.398	52.433	52.468	52.503	52.538	52.573	52.608	52.642	52.677	52.712	52.747	1300
1310	52.747	52.781	52.816	52.851	52.886	52.920	52.955	52.989	53.024	53.059	53.093	1310
1320	53.093	53.128	53.162	53.197	53.232	53.266	53.301	53.335	53.370	53.404	53.439	1320
1330	53.439	53.473	53.507	53.542	53.576	53.611	53.645	53.679	53.714	53.748	53.782	1330
1340	53.782	53.817	53.851	53.885	53.920	53.954	53.988	54.022	54.057	54.091	54.125	1340
1350	54.125	54.159	54.193	54.228	54.262	54.296	54.330	54.364	54.398	54.432	54.466	1350
1360	54.466	54.501	54.535	54.569	54.603	54.637	54.671	54.705	54.739	54.773	54.807	1360
1370	54.807	54.841	54.875									1370

T/C Type K - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 0 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.8 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-460							-6.458	-6.457	-6.457	-6.456	-6.456	-460
-450	-6.456	-6.455	-6.454	-6.454	-6.453	-6.452	-6.451	-6.450	-6.449	-6.448	-6.447	-450
-440	-6.447	-6.445	-6.444	-6.443	-6.441	-6.440	-6.438	-6.436	-6.435	-6.433	-6.431	-440
-430	-6.431	-6.429	-6.427	-6.425	-6.423	-6.421	-6.419	-6.416	-6.414	-6.411	-6.409	-430
-420	-6.409	-6.406	-6.404	-6.401	-6.398	-6.395	-6.392	-6.389	-6.386	-6.383	-6.380	-420
-410	-6.380	-6.377	-6.373	-6.370	-6.366	-6.363	-6.359	-6.355	-6.352	-6.348	-6.344	-410
-400	-6.344	-6.340	-6.336	-6.332	-6.328	-6.323	-6.319	-6.15	-6.310	-6.306	-6.301	-400
-390	-6.301	-6.296	-6.292	-6.287	-6.282	-6.277	-6.272	-6.267	-6.262	-6.257	-6.251	-390
-380	-6.251	-6.246	-6.241	-6.235	-6.230	-6.224	-6.219	-6.213	-6.207	-6.201	-6.195	-380
-370	-6.195	-6.189	-6.183	-6.177	-6.171	-6.165	-6.158	-6.152	-6.146	-6.139	-6.133	-370
-360	-6.133	-6.126	-6.119	-6.113	-6.106	-6.099	-6.092	-6.085	-6.078	-6.071	-6.064	-360
-350	-6.064	-6.057	-6.049	-6.042	-6.035	-6.027	-6.020	-6.012	-6.004	-5.997	-5.989	-350
-340	-5.989	-5.981	-5.973	-5.965	-5.957	-5.949	-5.941	-5.933	-5.925	-5.917	-5.908	-340
-330	-5.908	-5.900	-5.891	-5.883	-5.874	-5.866	-5.857	-5.848	-5.839	-5.831	-5.822	-330
-320	-5.822	-5.813	-5.804	-5.795	-5.786	-5.776	-5.767	-5.758	-5.748	-5.739	-5.730	-320
-310	-5.730	-5.720	-5.711	-5.701	-5.691	-5.682	-5.672	-5.662	-5.652	-5.642	-5.632	-310
-300	-5.632	-5.622	-5.612	-5.602	-5.592	-5.581	-5.571	-5.561	-5.550	-5.540	-5.529	-300
-290	-5.529	-5.519	-5.508	-5.497	-5.487	-5.476	-5.465	-5.454	-5.443	-5.432	-5.421	-290
-280	-5.421	-5.410	-5.399	-5.388	-5.376	-5.365	-5.354	-5.342	-5.331	-5.319	-5.308	-280
-270	-5.308	-5.296	-5.285	-5.273	-5.261	-5.249	-5.238	-5.226	-5.214	-5.202	-5.190	-270
-260	-5.190	-5.178	-5.165	-5.153	-5.141	-5.129	-5.116	-5.104	-5.092	-5.079	-5.067	-260
-250	-5.067	-5.054	-5.041	-5.029	-5.016	-5.003	-4.990	-4.978	-4.965	-4.952	-4.939	-250
-240	-4.939	-4.926	-4.912	-4.899	-4.886	-4.873	-4.860	-4.846	-4.833	-4.819	-4.806	-240
-230	-4.806	-4.792	-4.779	-4.765	-4.752	-4.738	-4.724	-4.710	-4.697	-4.683	-4.669	-230
-220	-4.669	-4.655	-4.641	-4.627	-4.613	-4.598	-4.584	-4.570	-4.556	-4.541	-4.527	-220
-210	-4.527	-4.512	-4.498	-4.484	-4.469	-4.454	-4.440	-4.425	-4.410	-4.396	-4.381	-210
-200	-4.381	-4.366	-4.351	-4.336	-4.321	-4.306	-4.291	-4.276	-4.261	-4.245	-4.230	-200
-190	-4.230	-4.215	-4.200	-4.184	-4.169	-4.153	-4.138	-4.122	-4.107	-4.091	-4.075	-190
-180	-4.075	-4.060	-4.044	-4.028	-4.012	-3.997	-3.981	-3.965	-3.949	-3.933	-3.917	-180
-170	-3.917	-3.901	-3.884	-3.868	-3.852	-3.836	-3.819	-3.803	-3.787	-3.770	-3.754	-170
-160	-3.754	-3.737	-3.721	-3.704	-3.688	-3.671	-3.654	-3.637	-3.621	-3.604	-3.587	-160
-150	-3.587	-3.570	-3.553	-3.536	-3.519	-3.502	-3.485	-3.468	-3.451	-3.434	-3.417	-150

Table 8.1.8 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-140	-3.417	-3.399	-3.382	-3.365	-3.347	-3.330	-3.312	-3.295	-3.277	-3.260	-3.242	-140
-130	-3.242	-3.225	-3.207	-3.189	-3.172	-3.154	-3.136	-3.118	-3.100	-3.082	-3.065	-130
-120	-3.065	-3.047	-3.029	-3.010	-2.992	-2.974	-2.956	-2.938	-2.920	-2.902	-2.883	-120
-110	-2.883	-2.865	-2.847	-2.828	-2.810	-2.791	-2.773	-2.754	-2.736	-2.717	-2.699	-110
-100	-2.699	-2.680	-2.661	-2.643	-2.624	-2.605	-2.586	-2.567	-2.549	-2.530	-2.511	-100
-90	-2.511	-2.492	-2.473	-2.454	-2.435	-2.416	-2.397	-2.377	-2.358	-2.339	-2.320	-90
-80	-2.320	-2.300	-2.281	-2.262	-2.243	-2.223	-2.204	-2.184	-2.165	-2.145	-2.126	-80
-70	-2.126	-2.106	-2.087	-2.067	-2.047	-2.028	-2.008	-1.988	-1.968	-1.949	-1.929	-70
-60	-1.929	-1.909	-1.889	-1.869	-1.849	-1.829	-1.809	-1.789	-1.769	-1.749	-1.729	-60
-50	-1.729	-1.709	-1.689	-1.669	-1.648	-1.628	-1.608	-1.588	-1.567	-1.547	-1.527	-50
-40	-1.527	-1.506	-1.486	-1.465	-1.445	-1.424	-1.404	-1.383	-1.363	-1.342	-1.322	-40
-30	-1.322	-1.301	-1.280	-1.260	-1.239	-1.218	-1.197	-1.177	-1.156	-1.135	-1.114	-30
-20	-1.114	-1.093	-1.072	-1.051	-1.031	-1.010	-0.989	-0.968	-0.946	-0.925	-0.904	-20
-10	-0.904	-0.883	-0.862	-0.841	-0.820	-0.799	-0.777	-0.756	-0.735	-0.714	-0.692	-10
0	-0.692	-0.671	-0.650	-0.628	-0.607	-0.585	-0.564	-0.543	-0.521	-0.500	-0.478	0
10	-0.478	-0.457	-0.435	-0.413	-0.392	-0.370	-0.349	-0.327	-0.305	-0.284	-0.262	10
20	-0.262	-0.240	-0.218	-0.197	-0.175	-0.153	-0.131	-0.109	-0.088	-0.066	-0.044	20
30	-0.044	-0.022	0.000	0.022	0.044	0.066	0.088	0.110	0.132	0.154	0.176	30
40	0.176	0.198	0.220	0.242	0.264	0.286	0.308	0.331	0.353	0.375	0.397	40
50	0.397	0.419	0.441	0.464	0.486	0.508	0.530	0.553	0.575	0.597	0.619	50
60	0.619	0.642	0.664	0.686	0.709	0.731	0.753	0.776	0.798	0.821	0.843	60
70	0.843	0.865	0.888	0.910	0.933	0.955	0.978	1.000	1.023	1.045	1.068	70
80	1.068	1.090	1.113	1.135	1.158	1.181	1.203	1.226	1.248	1.271	1.294	80
90	1.294	1.316	1.339	1.362	1.384	1.407	1.430	1.452	1.475	1.498	1.520	90
100	1.520	1.543	1.566	1.589	1.611	1.634	1.657	1.680	1.703	1.725	1.748	100
110	1.748	1.771	1.794	1.817	1.839	1.862	1.885	1.908	1.931	1.954	1.977	110
120	1.977	2.000	2.022	2.045	2.068	2.091	2.114	2.137	2.160	2.183	2.206	120
130	2.206	2.229	2.252	2.275	2.298	2.321	2.344	2.367	2.390	2.413	2.436	130
140	2.436	2.459	2.482	2.505	2.528	2.551	2.574	2.597	2.620	2.643	2.666	140
150	2.666	2.689	2.712	2.735	2.758	2.781	2.804	2.827	2.850	2.873	2.896	150
160	2.896	2.920	2.943	2.966	2.989	3.012	3.035	3.058	3.081	3.104	3.127	160
170	3.127	3.150	3.173	3.196	3.220	3.243	3.266	3.289	3.312	3.335	3.358	170
180	3.358	3.381	3.404	3.427	3.450	3.473	3.496	3.519	3.543	3.566	3.589	180
190	3.589	3.612	3.635	3.658	3.681	3.704	3.727	3.750	3.773	3.796	3.819	190
200	3.819	3.842	3.865	3.888	3.911	3.934	3.957	3.980	4.003	4.026	4.049	200
210	4.049	4.072	4.095	4.118	4.141	4.164	4.187	4.210	4.233	4.256	4.279	210
220	4.279	4.302	4.325	4.348	4.371	4.394	4.417	4.439	4.462	4.485	4.508	220
230	4.508	4.531	4.554	4.577	4.600	4.622	4.645	4.668	4.691	4.714	4.737	230
240	4.737	4.759	4.782	4.805	4.828	4.851	4.873	4.896	4.919	4.942	4.964	240
250	4.964	4.987	5.010	5.033	5.055	5.078	5.101	5.124	5.146	5.169	5.192	250
260	5.192	5.214	5.237	5.260	5.282	5.305	5.327	5.350	5.373	5.395	5.418	260
270	5.418	5.440	5.463	5.486	5.508	5.531	5.553	5.576	5.598	5.621	5.643	270
280	5.643	5.666	5.688	5.711	5.733	5.756	5.778	5.801	5.823	5.846	5.868	280
290	5.868	5.891	5.913	5.936	5.958	5.980	6.003	6.025	6.048	6.070	6.092	290
300	6.092	6.115	6.137	6.160	6.182	6.204	6.227	6.249	6.271	6.294	6.316	300
310	6.316	6.338	6.361	6.383	6.405	6.428	6.450	6.472	6.494	6.517	6.539	310
320	6.539	6.561	6.583	6.606	6.628	6.650	6.672	6.695	6.717	6.739	6.761	320
330	6.761	6.784	6.806	6.828	6.850	6.873	6.895	6.917	6.939	6.961	6.984	330
340	6.984	7.006	7.028	7.050	7.072	7.094	7.117	7.139	7.161	7.183	7.205	340
350	7.205	7.228	7.250	7.272	7.294	7.316	7.338	7.361	7.383	7.405	7.427	350
360	7.427	7.449	7.471	7.494	7.516	7.538	7.560	7.582	7.604	7.627	7.649	360
370	7.649	7.671	7.693	7.715	7.737	7.760	7.782	7.804	7.826	7.848	7.870	370
380	7.870	7.893	7.915	7.937	7.959	7.981	8.003	8.026	8.048	8.070	8.092	380

Table 8.1.8 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
390	8.092	8.114	8.137	8.159	8.181	8.203	8.225	8.248	8.270	8.292	8.314	390
400	8.314	8.336	8.359	8.381	8.403	8.425	8.448	8.470	8.492	8.514	8.537	400
410	8.537	8.559	8.581	8.603	8.626	8.648	8.670	8.692	8.715	8.737	8.759	410
420	8.759	8.782	8.804	8.826	8.849	8.871	8.893	8.916	8.938	8.960	8.983	420
430	8.983	9.005	9.027	9.050	9.072	9.094	9.117	9.139	9.161	9.184	9.206	430
440	9.206	9.229	9.251	9.273	9.296	9.318	9.341	9.363	9.385	9.408	9.430	440
450	9.430	9.453	9.475	9.498	9.520	9.543	9.565	9.588	9.610	9.633	9.655	450
460	9.655	9.678	9.700	9.723	9.745	9.768	9.790	9.813	9.835	9.858	9.880	460
470	9.880	9.903	9.926	9.948	9.971	9.993	10.016	10.038	10.061	10.084	10.106	470
480	10.106	10.129	10.151	10.174	10.197	10.219	10.242	10.265	10.287	10.310	10.333	480
490	10.333	10.355	10.378	10.401	10.423	10.446	10.469	10.491	10.514	10.537	10.560	490
500	10.560	10.582	10.605	10.628	10.650	10.673	10.696	10.719	10.741	10.764	10.787	500
510	10.787	10.810	10.833	10.855	10.878	10.901	10.924	10.947	10.969	10.992	11.015	510
520	11.015	11.038	11.061	11.083	11.106	11.129	11.152	11.175	11.198	11.221	11.243	520
530	11.243	11.266	11.289	11.312	11.335	11.358	11.381	11.404	11.426	11.449	11.472	530
540	11.472	11.495	11.518	11.541	11.564	11.587	11.610	11.633	11.656	11.679	11.702	540
550	11.702	11.725	11.748	11.770	11.793	11.816	11.839	11.862	11.885	11.908	11.931	550
560	11.931	11.954	11.977	12.000	12.023	12.046	12.069	12.092	12.115	12.138	12.161	560
570	12.161	12.184	12.207	12.230	12.254	12.277	12.300	12.323	12.346	12.369	12.392	570
580	12.392	12.415	12.438	12.461	12.484	12.507	12.530	12.553	12.576	12.599	12.623	580
590	12.623	12.646	12.669	12.692	12.715	12.738	12.761	12.784	12.807	12.831	12.854	590
600	12.854	12.877	12.900	12.923	12.946	12.969	12.992	13.016	13.039	13.062	13.085	600
610	13.085	13.108	13.131	13.154	13.178	13.201	13.224	13.247	13.270	13.93	13.317	610
620	13.317	13.340	13.363	13.386	13.409	13.433	13.456	13.479	13.502	13.525	13.549	620
630	13.549	13.572	13.595	13.618	13.641	13.665	13.688	13.711	13.734	13.757	13.781	630
640	13.781	13.804	13.827	13.850	13.874	13.897	13.920	13.943	13.967	13.990	14.013	640
650	14.013	14.036	14.060	14.083	14.106	14.129	14.153	14.176	14.199	14.222	14.246	650
660	14.246	14.269	14.292	14.316	14.339	14.362	14.385	14.409	14.432	14.455	14.479	660
670	14.479	14.502	14.525	14.548	14.572	14.595	14.618	14.642	14.665	14.688	14.712	670
680	14.712	14.735	14.758	14.782	14.805	14.828	14.852	14.875	14.898	14.922	14.945	680
690	14.945	14.968	14.992	15.015	15.038	15.062	15.085	15.108	15.132	15.155	15.178	690
700	15.178	15.202	15.225	15.248	15.272	15.295	15.318	15.342	15.365	15.389	15.412	700
710	15.412	15.435	15.459	15.482	15.505	15.529	15.552	15.576	15.599	15.622	15.646	710
720	15.646	15.669	15.693	15.716	15.739	15.763	15.786	15.810	15.833	15.856	15.880	720
730	15.880	15.903	15.927	15.950	15.974	15.997	16.020	16.044	16.067	16.091	16.114	730
740	16.114	16.138	16.161	16.184	16.208	16.231	16.255	16.278	16.302	16.325	16.349	740
750	16.349	16.372	16.395	16.419	16.442	16.466	16.489	16.513	16.536	16.560	16.583	750
760	16.583	16.607	16.630	16.654	16.677	16.700	16.724	16.747	16.771	16.794	16.818	760
770	16.818	16.841	16.865	16.888	16.912	16.935	16.959	16.982	17.006	17.029	17.053	770
780	17.053	17.076	17.100	17.123	17.147	17.170	17.194	17.217	17.241	17.264	17.288	780
790	17.288	17.311	17.335	17.358	17.382	17.406	17.429	17.453	17.476	17.500	17.523	790
800	17.523	17.547	17.570	17.594	17.617	17.641	17.664	17.688	17.711	17.735	17.759	800
810	17.759	17.782	17.806	17.829	17.853	17.876	17.900	17.923	17.947	17.971	17.994	810
820	17.994	18.018	18.041	18.065	18.088	18.112	18.136	18.159	18.183	18.206	18.230	820
830	18.230	18.253	18.277	18.301	18.324	18.348	18.371	18.395	18.418	18.442	18.466	830
840	18.466	18.489	18.513	18.536	18.560	18.584	18.607	18.631	18.654	18.678	18.702	840
850	18.702	18.725	18.749	18.772	18.796	18.820	18.843	18.867	18.890	18.914	18.938	850
860	18.938	18.961	18.985	19.008	19.032	19.056	19.079	19.103	19.127	19.150	19.174	860
870	19.174	19.197	19.221	19.245	19.268	19.292	19.316	19.339	19.363	19.386	19.410	870
880	19.410	19.434	19.457	19.481	19.505	19.528	19.552	19.576	19.599	19.623	19.646	880
890	19.646	19.670	19.694	19.717	19.741	19.765	19.788	19.812	19.836	19.859	19.883	890
900	19.883	19.907	19.930	19.954	19.978	20.001	20.025	20.049	20.072	20.096	20.120	900
910	20.120	20.143	20.167	20.190	20.214	20.238	20.261	20.285	20.309	20.332	20.356	910

Table 8.1.8 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
920	20.356	20.380	20.403	20.427	20.451	20.474	20.498	20.522	20.545	20.569	20.593	920
930	20.593	20.616	20.640	20.664	20.688	20.711	20.735	20.759	20.782	20.806	20.830	930
940	20.830	20.853	20.877	20.901	20.924	20.948	20.972	20.995	21.019	21.043	21.066	940
950	21.066	21.090	21.114	21.137	21.161	21.185	21.208	21.232	21.256	21.280	21.303	950
960	21.303	21.327	21.351	21.374	21.398	21.422	21.445	21.469	21.493	21.516	21.540	960
970	21.540	21.564	21.587	21.611	21.635	21.659	21.682	21.706	21.730	21.753	21.777	970
980	21.777	21.801	21.824	21.848	21.872	21.895	21.919	21.943	21.966	21.990	22.014	980
990	22.014	22.038	22.061	22.085	22.109	22.132	22.156	22.180	22.203	22.227	22.251	990
1000	22.251	22.274	22.298	22.322	22.346	22.369	22.393	22.417	22.440	22.464	22.488	1000
1010	22.488	22.511	22.535	22.559	22.582	22.606	22.630	22.654	22.677	22.701	22.725	1010
1020	22.725	22.748	22.772	22.796	22.819	22.843	22.867	22.890	22.914	22.938	22.961	1020
1030	22.961	22.985	23.009	23.032	23.056	23.080	23.104	23.127	23.151	23.175	23.198	1030
1040	23.198	23.222	23.246	23.269	23.293	23.317	23.340	23.364	23.388	23.411	23.435	1040
1050	23.435	23.459	23.482	23.506	23.530	23.553	23.577	23.601	23.624	23.648	23.672	1050
1060	23.672	23.695	23.719	23.743	23.766	23.790	23.814	23.837	23.861	23.885	23.908	1060
1070	23.908	23.932	23.956	23.979	24.003	24.027	24.050	24.074	24.098	24.121	24.145	1070
1080	24.145	24.169	24.192	24.216	24.240	24.263	24.287	24.311	24.334	24.358	24.382	1080
1090	24.382	24.405	24.429	24.453	24.476	24.500	24.523	24.547	24.571	24.594	24.618	1090
1100	24.618	24.642	24.665	24.689	24.713	24.736	24.760	24.783	24.807	24.831	24.854	1100
1110	24.854	24.878	24.902	24.925	24.949	24.972	24.996	25.020	25.043	25.067	25.091	1110
1120	25.091	25.114	25.138	25.161	25.185	25.209	25.232	25.256	25.279	25.303	25.327	1120
1130	25.327	25.350	25.374	25.397	25.421	25.445	25.468	25.492	25.515	25.539	25.563	1130
1140	25.563	25.586	25.610	25.633	25.657	25.681	25.704	25.728	25.751	25.775	25.799	1140
1150	25.799	25.822	25.846	25.869	25.893	25.916	25.940	25.964	25.987	26.011	26.034	1150
1160	26.034	26.058	26.081	26.105	26.128	26.152	26.176	26.199	26.223	26.246	26.270	1160
1170	26.270	26.293	26.317	26.340	26.364	26.387	26.411	26.435	26.458	26.482	26.505	1170
1180	26.505	26.529	26.552	26.576	26.599	26.623	26.646	26.670	26.693	26.717	26.740	1180
1190	26.740	26.764	26.787	26.811	26.834	26.858	26.881	26.905	26.928	26.952	26.975	1190
1200	26.975	26.999	27.022	27.046	27.069	27.093	27.116	27.140	27.163	27.187	27.210	1200
1210	27.210	27.234	27.257	27.281	27.304	27.328	27.351	27.375	27.398	27.422	27.445	1210
1220	27.445	27.468	27.492	27.515	27.539	27.562	27.586	27.609	27.633	27.656	27.679	1220
1230	27.679	27.703	27.726	27.750	27.773	27.797	27.820	27.843	27.867	27.890	27.914	1230
1240	27.914	27.937	27.961	27.984	28.007	28.031	28.054	28.078	28.101	28.124	28.148	1240
1250	28.148	28.171	28.195	28.218	28.241	28.265	28.288	28.311	28.335	28.358	28.382	1250
1260	28.382	28.405	28.428	28.452	28.475	28.498	28.522	28.545	28.569	28.592	28.615	1260
1270	28.615	28.639	28.662	28.685	28.709	28.732	28.755	28.779	28.802	28.825	28.849	1270
1280	28.849	28.872	28.895	28.919	28.942	28.965	28.988	29.012	29.035	29.058	29.082	1280
1290	29.082	29.105	29.128	29.152	29.175	29.198	29.221	29.245	29.268	29.291	29.315	1290
1300	29.315	29.338	29.361	29.384	29.408	29.431	29.454	29.477	29.501	29.524	29.547	1300
1310	29.547	29.570	29.594	29.617	29.640	29.663	29.687	29.710	29.733	29.756	29.780	1310
1320	29.780	29.803	29.826	29.849	29.872	29.896	29.919	29.942	29.965	29.989	30.012	1320
1330	30.012	30.035	30.058	30.081	30.104	30.128	30.151	30.174	30.197	30.220	30.244	1330
1340	30.244	30.267	30.290	30.313	30.336	30.359	30.383	30.406	30.429	30.452	30.475	1340
1350	30.475	30.498	30.521	30.545	30.568	30.591	30.614	30.637	30.660	30.683	30.706	1350
1360	30.706	30.730	30.753	30.776	30.799	30.822	30.845	30.868	30.891	30.914	30.937	1360
1370	30.937	30.961	30.984	31.007	31.030	31.053	31.076	31.099	31.122	31.145	31.168	1370
1380	31.168	31.191	31.214	31.237	31.260	31.283	31.306	31.329	31.353	31.376	31.399	1380
1390	31.399	31.422	31.445	31.468	31.491	31.514	31.537	31.560	31.583	31.606	31.629	1390
1400	31.629	31.652	31.675	31.698	31.721	31.744	31.767	31.790	31.813	31.836	31.859	1400
1410	31.859	31.882	31.905	31.927	31.950	31.973	31.996	32.019	32.042	32.065	32.088	1410
1420	32.088	32.111	32.134	32.157	32.180	32.203	32.226	32.249	32.272	32.294	32.317	1420
1430	32.317	32.340	32.363	32.386	32.409	32.432	32.455	32.478	32.501	32.523	32.546	1430
1440	32.546	32.569	32.592	32.615	32.638	32.661	32.683	32.706	32.729	32.752	32.775	1440

Table 8.1.8 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1450	32.775	32.798	32.821	32.843	32.866	32.889	32.912	32.935	32.958	32.980	33.003	1450
1460	33.003	33.026	33.049	33.072	33.094	33.117	33.140	33.163	33.186	33.208	33.231	1460
1470	33.231	33.254	33.277	33.300	33.322	33.345	33.368	33.391	33.413	33.436	33.459	1470
1480	33.459	33.482	33.504	33.527	33.550	33.573	33.595	33.618	33.641	33.664	33.686	1480
1490	33.686	33.709	33.732	33.754	33.777	33.800	33.823	33.845	33.868	33.891	33.913	1490
1500	33.913	33.936	33.959	33.981	34.004	34.027	34.049	34.072	34.095	34.117	34.140	1500
1510	34.140	34.163	34.185	34.208	34.231	34.253	34.276	34.299	34.321	34.344	34.366	1510
1520	34.366	34.389	34.412	34.434	34.457	34.480	34.502	34.525	34.547	34.570	34.593	1520
1530	34.593	34.615	34.638	34.660	34.683	34.705	34.728	34.751	34.773	34.796	34.818	1530
1540	34.818	34.841	34.863	34.886	34.909	34.931	34.954	34.976	34.999	35.021	35.044	1540
1550	35.044	35.066	35.089	35.111	35.134	35.156	35.179	35.201	35.224	35.246	35.269	1550
1560	35.269	35.291	35.314	35.336	35.359	35.381	35.404	35.426	35.449	35.471	35.494	1560
1570	35.494	35.516	35.539	35.561	35.583	35.606	35.628	35.651	35.673	35.696	35.718	1570
1580	35.718	35.741	35.763	35.785	35.808	35.830	35.853	35.875	35.897	35.920	35.942	1580
1590	35.942	35.965	35.987	36.009	36.032	36.054	36.077	36.099	36.121	36.144	36.166	1590
1600	36.166	36.188	36.211	36.233	36.256	36.278	36.300	36.323	36.345	36.367	36.390	1600
1610	36.390	36.412	36.434	36.457	36.479	36.501	36.524	36.546	36.568	36.590	36.613	1610
1620	36.613	36.635	36.657	36.680	36.702	36.724	36.746	36.769	36.791	36.813	36.836	1620
1630	36.836	36.858	36.880	36.902	36.925	36.947	36.969	36.991	37.014	37.036	37.058	1630
1640	37.058	37.080	37.103	37.125	37.147	37.169	37.191	37.214	37.236	37.258	37.280	1640
1650	37.280	37.303	37.325	37.347	37.369	37.391	37.413	37.436	37.458	37.480	37.502	1650
1660	37.502	37.524	37.547	37.569	37.591	37.613	37.635	37.657	37.679	37.702	37.724	1660
1670	37.724	37.746	37.768	37.790	37.812	37.834	37.857	37.879	37.901	37.923	37.945	1670
1680	37.945	37.967	37.989	38.011	38.033	38.055	38.078	38.100	38.122	38.144	38.166	1680
1690	38.166	38.188	38.210	38.232	38.254	38.276	38.298	38.320	38.342	38.364	38.387	1690
1700	38.387	38.409	38.431	38.453	38.475	38.497	38.519	38.541	38.563	38.585	38.607	1700
1710	38.607	38.629	38.651	38.673	38.695	38.717	38.739	38.761	38.783	38.805	38.827	1710
1720	38.827	38.849	38.871	38.893	38.915	38.937	38.959	38.981	39.003	39.024	39.046	1720
1730	39.046	39.068	39.090	39.112	39.134	39.156	39.178	39.200	39.222	39.244	39.266	1730
1740	39.266	39.288	39.310	39.331	39.353	39.375	39.397	39.419	39.441	39.463	39.485	1740
1750	39.485	39.507	39.529	39.550	39.572	39.594	39.616	39.638	39.660	39.682	39.703	1750
1760	39.703	39.725	39.747	39.769	39.791	39.813	39.835	39.856	39.878	39.900	39.922	1760
1770	39.922	39.944	39.965	39.987	40.009	40.031	40.053	40.075	40.096	40.118	40.140	1770
1780	40.140	40.162	40.183	40.205	40.227	40.249	40.271	40.292	40.314	40.336	40.358	1780
1790	40.358	40.379	40.401	40.423	40.445	40.466	40.488	40.510	40.532	40.553	40.575	1790
1800	40.575	40.597	40.619	40.640	40.662	40.684	40.705	40.727	40.749	40.770	40.792	1800
1810	40.792	40.814	40.836	40.857	40.879	40.901	40.922	40.944	40.966	40.987	41.009	1810
1820	41.009	41.031	41.052	41.074	41.096	41.117	41.139	41.161	41.182	41.204	41.225	1820
1830	41.225	41.247	41.269	41.290	41.312	41.334	41.355	41.377	41.398	41.420	41.442	1830
1840	41.442	41.463	41.485	41.506	41.528	41.550	41.571	41.593	41.614	41.636	41.657	1840
1850	41.657	41.679	41.701	41.722	41.744	41.765	41.787	41.808	41.830	41.851	41.873	1850
1860	41.873	41.895	41.916	41.938	41.959	41.981	42.002	42.024	42.045	42.067	42.088	1860
1870	42.088	42.110	42.131	42.153	42.174	42.196	42.217	42.239	42.260	42.282	42.303	1870
1880	42.303	42.325	42.346	42.367	42.389	42.410	42.432	42.453	42.475	42.496	42.518	1880
1890	42.518	42.539	42.560	42.582	42.603	42.625	42.646	42.668	42.689	42.710	42.732	1890
1900	42.732	42.753	42.775	42.796	42.817	42.839	42.860	42.882	42.903	42.924	42.946	1900
1910	42.946	42.967	42.989	43.010	43.031	43.053	43.074	43.095	43.117	43.138	43.159	1910
1920	43.159	43.181	43.202	43.223	43.245	43.266	43.287	43.309	43.330	43.351	43.373	1920
1930	43.373	43.394	43.415	43.436	43.458	43.479	43.500	43.522	43.543	43.564	43.585	1930
1940	43.585	43.607	43.628	43.649	43.671	43.692	43.713	43.734	43.756	43.777	43.798	1940
1950	43.798	43.819	43.841	43.862	43.883	43.904	43.925	43.947	43.968	43.989	44.010	1950
1960	44.010	44.031	44.053	44.074	44.095	44.116	44.137	44.159	44.180	44.201	44.222	1960
1970	44.222	44.243	44.265	44.286	44.307	44.328	44.349	44.370	44.391	44.413	44.434	1970

Table 8.1.8 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1980	44.434	44.455	44.476	44.497	44.518	44.539	44.560	44.582	44.603	44.624	44.645	1980
1990	44.645	44.666	44.687	44.708	44.729	44.750	44.771	44.793	44.814	44.835	44.856	1990
2000	44.856	44.877	44.898	44.919	44.940	44.961	44.982	45.003	45.024	45.045	45.066	2000
2010	45.066	45.087	45.108	45.129	45.150	45.171	45.192	45.213	45.234	45.255	45.276	2010
2020	45.276	45.297	45.318	45.339	45.360	45.381	45.402	45.423	45.444	45.465	45.486	2020
2030	45.486	45.507	45.528	45.549	45.570	45.591	45.612	45.633	45.654	45.675	45.695	2030
2040	45.695	45.716	45.737	45.758	45.779	45.800	45.821	45.842	45.863	45.884	45.904	2040
2050	45.904	45.925	45.946	45.967	45.988	46.009	46.030	46.051	46.071	46.092	46.113	2050
2060	46.113	46.134	46.155	46.176	46.196	46.217	46.238	46.259	46.280	46.300	46.321	2060
2070	46.321	46.342	46.363	46.384	46.404	46.425	46.446	46.467	46.488	46.508	46.529	2070
2080	46.529	46.550	46.571	46.591	46.612	46.633	46.654	46.674	46.695	46.716	46.737	2080
2090	46.737	46.757	46.778	46.799	46.819	46.840	46.861	46.881	46.902	46.923	46.944	2090
2100	46.944	46.964	46.985	47.006	47.026	47.047	47.068	47.088	47.109	47.130	47.150	2100
2110	47.150	47.171	47.191	47.212	47.233	47.253	47.274	47.295	47.315	47.336	47.356	2110
2120	47.356	47.377	47.398	47.418	47.439	47.459	47.480	47.500	47.521	47.542	47.562	2120
2130	47.562	47.583	47.603	47.624	47.644	47.665	47.685	47.706	47.726	47.747	47.767	2130
2140	47.767	47.788	47.808	47.829	47.849	47.870	47.890	47.911	47.931	47.952	47.972	2140
2150	47.972	47.993	48.013	48.034	48.054	48.075	48.095	48.116	48.136	48.156	48.177	2150
2160	48.177	48.197	48.218	48.238	48.258	48.279	48.299	48.320	48.340	48.360	48.381	2160
2170	48.381	48.401	48.422	48.442	48.462	48.483	48.503	48.523	48.544	48.564	48.584	2170
2180	48.584	48.605	48.625	48.645	48.666	48.686	48.706	48.727	48.747	48.767	48.787	2180
2190	48.787	48.808	48.828	48.848	48.869	48.889	48.909	48.929	48.950	48.970	48.990	2190
2200	48.990	49.010	49.031	49.051	49.071	49.091	49.111	49.132	49.152	49.172	49.192	2200
2210	49.192	49.212	49.233	49.253	49.273	49.293	49.313	49.333	49.354	49.374	49.394	2210
2220	49.394	49.414	49.434	49.454	49.474	49.495	49.515	49.535	49.555	49.575	49.595	2220
2230	49.595	49.615	49.635	49.655	49.675	49.696	49.716	49.736	49.756	49.776	49.796	2230
2240	49.796	49.816	49.836	49.856	49.876	49.896	49.916	49.936	49.956	49.976	49.996	2240
2250	49.996	50.016	50.036	50.056	50.076	50.096	50.116	50.136	50.156	50.176	50.196	2250
2260	50.196	50.216	50.236	50.256	50.276	50.296	50.315	50.335	50.355	50.375	50.395	2260
2270	50.395	50.415	50.435	50.455	50.475	50.494	50.514	50.534	50.554	50.574	50.594	2270
2280	50.594	50.614	50.633	50.653	50.673	50.693	50.713	50.733	50.752	50.772	50.792	2280
2290	50.792	50.812	50.832	50.851	50.871	50.891	50.911	50.930	50.950	50.970	50.990	2290
2300	50.990	51.009	51.029	51.049	51.069	51.088	51.108	51.128	51.148	51.167	51.187	2300
2310	51.187	51.207	51.226	51.246	51.266	51.285	51.305	51.325	51.344	51.364	51.384	2310
2320	51.384	51.403	51.423	51.443	51.462	51.482	51.501	51.521	51.541	51.560	51.580	2320
2330	51.580	51.599	51.619	51.639	51.658	51.678	51.697	51.717	51.736	51.756	51.776	2330
2340	51.776	51.795	51.815	51.834	51.854	51.873	51.893	51.912	51.932	51.951	51.971	2340
2350	51.971	51.990	52.010	52.029	52.049	52.068	52.088	52.107	52.127	52.146	52.165	2350
2360	52.165	52.185	52.204	52.224	52.243	52.263	52.282	52.301	52.321	52.340	52.360	2360
2370	52.360	52.379	52.398	52.418	52.437	52.457	52.476	52.495	52.515	52.534	52.553	2370
2380	52.553	52.573	52.592	52.611	52.631	52.650	52.669	52.689	52.708	52.727	52.747	2380
2390	52.747	52.766	52.785	52.805	52.824	52.843	52.862	52.882	52.901	52.920	52.939	2390
2400	52.939	52.959	52.978	52.997	53.016	53.136	53.055	53.074	53.093	53.113	53.132	2400
2410	53.132	53.151	53.170	53.189	53.209	53.228	53.247	53.266	53.285	53.304	53.324	2410
2420	53.324	53.343	53.362	53.381	53.400	53.419	53.439	53.458	53.477	53.496	53.515	2420
2430	53.515	53.534	53.553	53.572	53.592	53.611	53.630	53.649	53.668	53.687	53.706	2430
2440	53.706	53.725	53.744	53.763	53.782	53.801	53.821	53.840	53.859	53.878	53.897	2440
2450	53.897	53.916	53.935	53.954	53.973	53.992	54.011	54.030	54.049	54.068	54.087	2450
2460	54.087	54.106	54.125	54.144	54.163	54.182	54.201	54.220	54.239	54.258	54.277	2460
2470	54.277	54.296	54.315	54.334	54.353	54.372	54.391	54.410	54.429	54.447	54.466	2470
2480	54.466	54.485	54.504	54.523	54.542	54.561	54.580	54.599	54.618	54.637	54.656	2480
2490	54.656	54.675	54.694	54.712	54.731	54.750	54.769	54.788	54.807	54.826	54.845	2490
2500	54.845	54.864	54.882									2500

T/C Type N - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: BS 4937 part 8

Table 8.1.9 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-270	-4.345	-4.345	-4.344	-4.344	-4.343	-4.342	-4.341	-4.340	-4.339	-4.337	-4.336	-270
-260	-4.336	-4.334	-4.332	-4.330	-4.328	-4.326	-4.324	-4.321	-4.319	-4.316	-4.313	-260
-250	-4.313	-4.310	-4.307	-4.304	-4.300	-4.297	-4.293	-4.289	-4.285	-4.281	-4.277	-250
-240	-4.277	-4.273	-4.268	-4.263	-4.259	-4.254	-4.248	-4.243	-4.238	-4.232	-4.227	-240
-230	-4.277	-4.221	-4.215	-4.209	-4.202	-4.196	-4.189	-4.183	-4.176	-4.169	-4.162	-230
-220	-4.162	-4.155	-4.147	-4.140	-4.132	-4.124	-4.116	-4.108	-4.100	-4.091	-4.083	-220
-210	-4.083	-4.074	-4.066	-4.057	-4.048	-4.038	-4.029	-4.020	-4.010	-4.000	-3.990	-210
-200	-3.990	-3.980	-3.970	-3.960	-3.950	-3.939	-3.928	-3.918	-3.907	-3.896	-3.884	-200
-190	-3.884	-3.873	-3.862	-3.850	-3.838	-3.827	-3.815	-3.803	-3.790	-3.778	-3.766	-190
-180	-3.766	-3.753	-3.740	-3.727	-3.715	-3.701	-3.688	-3.675	-3.661	-3.648	-3.634	-180
-170	-3.634	-3.620	-3.607	-3.592	-3.578	-3.564	-3.550	-3.535	-3.521	-3.506	-3.491	-170
-160	-3.491	-3.476	-3.461	-3.446	-3.430	-3.415	-3.399	-3.384	-3.368	-3.352	-3.336	-160
-150	-3.336	-3.320	-3.304	-3.288	-3.271	-3.255	-3.238	-3.221	-3.204	-3.187	-3.170	-150
-140	-3.170	-3.153	-3.136	-3.118	-3.101	-3.083	-3.066	-3.048	-3.030	-3.012	-2.994	-140
-130	-2.994	-2.976	-2.957	-2.939	-2.921	-2.902	-2.883	-2.864	-2.846	-2.827	-2.807	-130
-120	-2.807	-2.788	-2.769	-2.750	-2.730	-2.711	-2.691	-2.671	-2.651	-2.632	-2.612	-120
-110	-2.612	-2.591	-2.571	-2.551	-2.531	-2.510	-2.490	-2.469	-2.448	-2.427	-2.407	-110
-100	-2.407	-2.386	-2.365	-2.343	-2.322	-2.301	-2.280	-2.258	-2.237	-2.215	-2.193	-100
-90	-2.193	-2.171	-2.150	-2.128	-2.106	-2.084	-2.061	-2.039	-2.017	-1.995	-1.972	-90
-80	-1.972	-1.950	-1.927	-1.904	-1.882	-1.859	-1.836	-1.813	-1.790	-1.767	-1.744	-80
-70	-1.744	-1.721	-1.697	-1.674	-1.651	-1.627	-1.604	-1.580	-1.556	-1.533	-1.509	-70
-60	-1.509	-1.485	-1.461	-1.437	-1.413	-1.389	-1.365	-1.341	-1.317	-1.293	-1.268	-60
-50	-1.268	-1.244	-1.220	-1.195	-1.171	-1.146	-1.121	-1.097	-1.072	-1.047	-1.023	-50
-40	-1.023	-0.998	-0.973	-0.948	-0.923	-0.898	-0.873	-0.848	-0.823	-0.797	-0.772	-40
-30	-0.772	-0.747	-0.722	-0.696	-0.671	-0.646	-0.620	-0.595	-0.569	-0.544	-0.518	-30
-20	-0.518	-0.492	-0.467	-0.441	-0.415	-0.390	-0.364	-0.338	-0.312	-0.286	-0.260	-20
-10	-0.260	-0.234	-0.208	-0.183	-0.157	-0.130	-0.104	-0.078	-0.052	-0.026	0.000	-10
0	0.000	0.026	0.052	0.078	0.104	0.130	0.156	0.182	0.208	0.234	0.261	0
10	0.261	0.287	0.313	0.340	0.366	0.392	0.419	0.445	0.472	0.498	0.525	10
20	0.525	0.551	0.578	0.605	0.632	0.658	0.685	0.712	0.739	0.766	0.793	20
30	0.793	0.820	0.847	0.874	0.901	0.928	0.955	0.982	1.010	1.037	1.064	30
40	1.064	1.092	1.119	1.146	1.174	1.201	1.229	1.256	1.284	1.312	1.339	40
50	1.339	1.367	1.395	1.423	1.451	1.479	1.506	1.534	1.562	1.591	1.619	50
60	1.619	1.647	1.675	1.703	1.731	1.760	1.788	1.816	1.845	1.873	1.902	60
70	1.902	1.930	1.959	1.987	2.016	2.045	2.073	2.102	2.131	2.160	2.188	70
80	2.188	2.217	2.246	2.275	2.304	2.333	2.362	2.392	2.421	2.450	2.479	80
90	2.479	2.508	2.538	2.567	2.596	2.626	2.655	2.685	2.714	2.744	2.774	90
100	2.774	2.803	2.833	2.863	2.892	2.922	2.952	2.982	3.012	3.042	3.072	100
110	3.072	3.102	3.132	3.162	3.192	3.222	3.252	3.283	3.313	3.343	3.374	110
120	3.374	3.404	3.434	3.465	3.495	3.526	3.557	3.587	3.618	3.648	3.679	120
130	3.679	3.710	3.741	3.772	3.802	3.833	3.864	3.895	3.926	3.957	3.988	130
140	3.988	4.019	4.050	4.082	4.113	4.144	4.175	4.207	4.238	4.269	4.301	140
150	4.301	4.332	4.364	4.395	4.427	4.458	4.490	4.521	4.553	4.585	4.617	150
160	4.617	4.648	4.680	4.712	4.744	4.776	4.808	4.840	4.872	4.904	4.936	160
170	4.936	4.968	5.000	5.032	5.064	5.097	5.129	5.161	5.193	5.226	5.258	170
180	5.258	5.290	5.323	5.355	5.388	5.420	5.453	5.486	5.518	5.551	5.584	180
190	5.584	5.616	5.649	5.682	5.715	5.747	5.780	5.813	5.846	5.879	5.912	190

Table 8.1.9 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
200	5.912	5.945	5.978	6.011	6.044	6.077	6.110	6.144	6.177	6.210	6.243	200
210	6.243	6.277	6.310	6.343	6.377	6.410	6.443	6.477	6.510	6.544	6.577	210
220	6.577	6.611	6.645	6.678	6.712	6.745	6.779	6.813	6.847	6.880	6.914	220
230	6.914	6.948	6.982	7.016	7.050	7.084	7.118	7.152	7.186	7.220	7.254	230
240	7.254	7.288	7.322	7.356	7.390	7.424	7.458	7.493	7.527	7.561	7.596	240
250	7.596	7.630	7.664	7.699	7.733	7.767	7.802	7.836	7.871	7.905	7.940	250
260	7.940	7.975	8.009	8.044	8.078	8.113	8.148	8.182	8.217	8.252	8.287	260
270	8.287	8.321	8.356	8.391	8.426	8.461	8.496	8.531	8.566	8.601	8.636	270
280	8.636	8.671	8.706	8.741	8.776	8.811	8.846	8.881	8.916	8.952	8.987	280
290	8.987	9.022	9.057	9.093	9.128	9.163	9.198	9.234	9.269	9.305	9.340	290
300	9.340	9.375	9.411	9.446	9.482	9.517	9.553	9.589	9.624	9.660	9.695	300
310	9.695	9.731	9.767	9.802	9.838	9.874	9.909	9.945	9.981	10.017	10.053	310
320	10.053	10.088	10.124	10.160	10.196	10.232	10.268	10.304	10.340	10.376	10.412	320
330	10.412	10.448	10.484	10.520	10.556	10.592	10.628	10.664	10.700	10.736	10.772	330
340	10.772	10.809	10.845	10.881	10.917	10.954	10.990	11.026	11.062	11.099	11.135	340
350	11.135	11.171	11.208	11.244	11.281	11.317	11.354	11.390	11.426	11.463	11.499	350
360	11.499	11.536	11.572	11.609	11.646	11.682	11.719	11.755	11.792	11.829	11.865	360
370	11.865	11.902	11.939	11.975	12.012	12.049	12.086	12.122	12.159	12.196	12.233	370
380	12.233	12.270	12.306	12.343	12.380	12.417	12.454	12.491	12.528	12.565	12.602	380
390	12.602	12.639	12.676	12.713	12.750	12.787	12.824	12.861	12.898	12.935	12.972	390
400	12.972	13.009	13.046	13.084	13.121	13.158	13.195	13.232	13.269	13.307	13.344	400
410	13.344	13.381	13.418	13.456	13.493	13.530	13.568	13.605	13.642	13.680	13.717	410
420	13.717	13.754	13.792	13.829	13.867	13.904	13.942	13.979	14.017	14.054	14.091	420
430	14.091	14.129	14.167	14.204	14.242	14.279	14.317	14.354	14.392	14.430	14.467	430
440	14.467	14.505	14.542	14.580	14.618	14.655	14.693	14.731	14.769	14.806	14.844	440
450	14.844	14.882	14.919	14.957	14.995	15.033	15.071	15.108	15.146	15.184	15.222	450
460	15.222	15.260	15.298	15.336	15.373	15.411	15.449	15.487	15.525	15.563	15.601	460
470	15.601	15.639	15.677	15.715	15.753	15.791	15.829	15.867	15.905	15.943	15.981	470
480	15.981	16.019	16.057	16.095	16.133	16.172	16.210	16.248	16.286	16.324	16.362	480
490	16.362	16.400	16.439	16.477	16.515	16.553	16.591	16.630	16.668	16.706	16.744	490
500	16.744	16.783	16.821	16.859	16.897	16.936	16.974	17.012	17.051	17.089	17.127	500
510	17.127	17.166	17.204	17.243	17.281	17.319	17.358	17.396	17.434	17.473	17.511	510
520	17.511	17.550	17.588	17.627	17.665	17.704	17.742	17.781	17.819	17.858	17.896	520
530	17.896	17.935	17.973	18.012	18.050	18.089	18.127	18.166	18.204	18.243	18.282	530
540	18.282	18.320	18.359	18.397	18.436	18.475	18.513	18.552	18.591	18.629	18.668	540
550	18.668	18.707	18.745	18.784	18.823	18.861	18.900	18.939	18.977	19.016	19.055	550
560	19.055	19.094	19.132	19.171	19.210	19.249	19.287	19.326	19.365	19.404	19.443	560
570	19.443	19.481	19.520	19.559	19.598	19.637	19.676	19.714	19.753	19.792	19.831	570
580	19.831	19.870	19.909	19.948	19.986	20.025	20.064	20.103	20.142	20.181	20.220	580
590	20.220	20.259	20.298	20.337	20.376	20.415	20.453	20.492	20.531	20.570	20.609	590
600	20.609	20.648	20.687	20.726	20.765	20.804	20.843	20.882	20.921	20.960	20.999	600
610	20.999	21.038	21.077	21.116	21.155	21.195	21.234	21.273	21.312	21.351	21.390	610
620	21.390	21.429	21.468	21.507	21.546	21.585	21.624	21.663	21.702	21.742	21.781	620
630	21.781	21.820	21.859	21.898	21.937	21.976	22.015	22.055	22.094	22.133	22.172	630
640	22.172	22.211	22.250	22.289	22.329	22.368	22.407	22.446	22.485	22.524	22.564	640
650	22.564	22.603	22.642	22.681	22.720	22.760	22.799	22.838	22.877	22.916	22.956	650
660	22.956	22.995	23.034	23.073	23.112	23.152	23.191	23.230	23.269	23.309	23.348	660
670	23.348	23.387	23.426	23.466	23.505	23.544	23.583	23.623	23.662	23.701	23.740	670
680	23.740	23.780	23.819	23.858	23.897	23.937	23.976	24.015	24.054	24.094	24.133	680
690	24.133	24.172	24.212	24.251	24.290	24.329	24.369	24.408	24.447	24.487	24.526	690
700	24.526	24.565	24.604	24.644	24.683	24.722	24.762	24.801	24.840	24.879	24.919	700
710	24.919	24.958	24.997	25.037	25.076	25.115	25.155	25.194	25.233	25.273	25.312	710
720	25.312	25.351	25.391	25.430	25.469	25.508	25.548	25.587	25.626	25.666	25.705	720

Table 8.1.9 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
730	25.705	25.744	25.784	25.823	25.862	25.902	25.941	25.980	26.020	26.059	26.098	730
740	26.098	26.138	26.177	26.216	26.255	26.295	26.334	26.373	26.413	26.452	26.491	740
750	26.491	26.531	26.570	26.609	26.649	26.688	26.727	26.767	26.806	26.845	26.885	750
760	26.885	26.924	26.963	27.002	27.042	27.081	27.120	27.160	27.199	27.238	27.278	760
770	27.278	27.317	27.356	27.396	27.435	27.474	27.513	27.553	27.592	27.631	27.671	770
780	27.671	27.710	27.749	27.788	27.828	27.867	27.906	27.946	27.985	28.024	28.063	780
790	28.063	28.103	28.142	28.181	28.221	28.260	28.299	28.338	28.378	28.417	28.456	790
800	28.456	28.495	28.535	28.574	28.613	28.652	28.692	28.731	28.770	28.809	28.849	800
810	28.849	28.888	28.927	28.966	29.006	29.045	29.084	29.123	29.163	29.202	29.241	810
820	29.241	29.280	29.319	29.359	29.398	29.437	29.476	29.516	29.555	29.594	29.633	820
830	29.633	29.672	29.712	29.751	29.790	29.829	29.868	29.908	29.947	29.986	30.025	830
840	30.025	30.064	30.103	30.143	30.182	30.221	30.260	30.299	30.338	30.378	30.417	840
850	30.417	30.456	30.495	30.534	30.573	30.612	30.652	30.691	30.730	30.769	30.808	850
860	30.808	30.847	30.886	30.925	30.964	31.004	31.043	31.082	31.121	31.160	31.199	860
870	31.199	31.238	31.277	31.316	31.355	31.394	31.434	31.473	31.512	31.551	31.590	870
880	31.590	31.629	31.668	31.707	31.746	31.785	31.824	31.863	31.902	31.941	31.980	880
890	31.980	32.019	32.058	32.097	32.136	32.175	32.214	32.253	32.292	32.331	32.370	890
900	32.370	32.409	32.448	32.487	32.526	32.565	32.604	32.643	32.682	32.721	32.760	900
910	32.760	32.799	32.838	32.877	32.916	32.955	32.993	33.032	33.071	33.110	33.149	910
920	33.149	33.188	33.227	33.266	33.305	33.344	33.382	33.421	33.460	33.499	33.538	920
930	33.538	33.577	33.616	33.655	33.693	33.732	33.771	33.810	33.849	33.888	33.926	930
940	33.926	33.965	34.004	34.043	34.082	34.121	34.159	34.198	34.237	34.276	34.315	940
950	34.315	34.353	34.392	34.431	34.470	34.508	34.547	34.586	34.625	34.663	34.702	950
960	34.702	34.741	34.780	34.818	34.857	34.896	34.935	34.973	35.012	35.051	35.089	960
970	35.089	35.128	35.167	35.205	35.244	35.283	35.321	35.360	35.399	35.437	35.476	970
980	35.476	35.515	35.553	35.592	35.631	35.669	35.708	35.747	35.785	35.824	35.862	980
990	35.862	35.901	35.940	35.978	36.017	36.055	36.094	36.132	36.171	36.210	36.248	990
1000	36.248	36.287	36.325	36.364	36.402	36.441	36.479	36.518	36.556	36.595	36.633	1000
1010	36.633	36.672	36.710	36.749	36.787	36.826	36.864	36.903	36.941	36.980	37.018	1010
1020	37.018	37.057	37.095	37.134	37.172	37.210	37.249	37.287	37.326	37.364	37.402	1020
1030	37.402	37.441	37.479	37.518	37.556	37.594	37.633	37.671	37.710	37.748	37.786	1030
1040	37.786	37.825	37.863	37.901	37.940	37.978	38.016	38.055	38.093	38.131	38.169	1040
1050	38.169	38.208	38.246	38.284	38.323	38.361	38.399	38.437	38.476	38.514	38.552	1050
1060	38.552	38.590	38.628	38.667	38.705	38.743	38.781	38.819	38.858	38.896	38.934	1060
1070	38.934	38.972	39.010	39.049	39.087	39.125	39.163	39.201	39.239	39.277	39.315	1070
1080	39.315	39.354	39.392	39.430	39.468	39.506	39.544	39.582	39.620	39.658	39.696	1080
1090	39.696	39.734	39.772	39.810	39.848	39.886	39.924	39.962	40.000	40.038	40.076	1090
1100	40.076	40.114	40.152	40.190	40.228	40.266	40.304	40.342	40.380	40.418	40.456	1100
1110	40.456	40.494	40.532	40.570	40.607	40.645	40.683	40.721	40.759	40.797	40.835	1110
1120	40.835	40.872	40.910	40.948	40.986	41.024	41.062	41.099	41.137	41.175	41.213	1120
1130	41.213	41.250	41.288	41.326	41.364	41.401	41.439	41.477	41.515	41.552	41.590	1130
1140	41.590	41.628	41.665	41.703	41.741	41.778	41.816	41.854	41.891	41.929	41.966	1140
1150	41.966	42.004	42.042	42.079	42.117	42.154	42.192	42.229	42.267	42.305	42.342	1150
1160	42.342	42.380	42.417	42.455	42.492	42.530	42.567	42.605	42.642	42.680	42.717	1160
1170	42.717	42.754	42.792	42.829	42.867	42.904	42.941	42.979	43.016	43.054	43.091	1170
1180	43.091	43.128	43.166	43.203	43.240	43.278	43.315	43.352	43.389	43.427	43.464	1180
1190	43.464	43.501	43.538	43.576	43.613	43.650	43.687	43.725	43.762	43.799	43.836	1190
1200	43.836	43.873	43.910	43.948	43.985	44.022	44.059	44.096	44.133	44.170	44.207	1200
1210	44.207	44.244	44.281	44.318	44.355	44.393	44.430	44.467	44.504	44.541	44.577	1210
1220	44.577	44.614	44.651	44.688	44.725	44.762	44.799	44.836	44.873	44.910	44.947	1220
1230	44.947	44.984	45.020	45.057	45.094	45.131	45.168	45.204	45.241	45.278	45.315	1230
1240	45.315	45.352	45.388	45.425	45.462	45.498	45.535	45.572	45.609	45.645	45.682	1240
1250	45.682	45.719	45.755	45.792	45.828	45.865	45.902	45.938	45.975	46.011	46.048	1250

Table 8.1.9 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1260	46.048	46.085	46.121	46.158	46.194	46.231	46.267	46.304	46.340	46.377	46.413	1260
1270	46.413	46.449	46.486	46.522	46.559	46.595	46.631	46.668	46.704	46.741	46.777	1270
1280	46.777	46.813	46.850	46.886	46.922	46.959	46.995	47.031	47.067	47.104	47.140	1280
1290	47.140	47.176	47.212	47.249	47.285	47.321	47.357	47.393	47.430	47.466	47.502	1290

T/C Type N - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: BS 4937 part 8

Table 8.1.10 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-460							-4.345	-4.345	-4.345	-4.344	-4.344	-460
-450	-4.344	-4.344	-4.343	-4.343	-4.343	-4.342	-4.341	-4.341	-4.340	-4.340	-4.339	-450
-440	-4.339	-4.338	-4.337	-4.337	-4.336	-4.335	-4.334	-4.333	-4.332	-4.332	-4.330	-440
-430	-4.330	-4.329	-4.327	-4.326	-4.325	-4.324	-4.322	-4.321	-4.319	-4.318	-4.316	-430
-420	-4.316	-4.315	-4.313	-4.312	-4.310	-4.308	-4.306	-4.305	-4.303	-4.301	-4.299	-420
-410	-4.299	-4.297	-4.295	-4.293	-4.291	-4.289	-4.286	-4.284	-4.282	-4.279	-4.277	-410
-400	-4.277	-4.275	-4.272	-4.270	-4.267	-4.264	-4.262	-4.259	-4.256	-4.254	-4.251	-400
-390	-4.251	-4.248	-4.245	-4.242	-4.239	-4.236	-4.233	-4.230	-4.227	-4.223	-4.220	-390
-380	-4.220	-4.217	-4.213	-4.210	-4.207	-4.203	4.200	4.196	4.192	4.189	4.185	-380
370	4.185	4.181	4.177	4.174	4.170	4.166	4.162	4.158	4.154	4.150	4.145	370
-360	4.145	4.141	4.137	4.133	4.128	4.124	4.120	4.115	4.111	4.106	4.102	-360
-350	4.102	4.097	4.092	4.088	4.083	4.078	4.073	4.058	4.064	4.059	4.054	-350
-340	4.054	4.049	4.043	4.038	4.033	4.028	4.023	4.017	4.012	4.007	4.001	-340
-330	4.001	-3.996	-3.990	-3.985	-3.979	-3.974	-3.968	-3.962	-3.957	-3.951	-3.945	-330
-320	-3.945	-3.939	-3.933	-3.927	-3.921	-3.915	-3.909	-3.903	-3.897	-3.891	-3.884	-320
-310	-3.884	-3.878	-3.872	-3.865	-3.859	-3.853	-3.846	-3.840	-3.833	-3.827	-3.820	-310
-300	-3.820	-3.813	-3.807	-3.800	-3.793	-3.786	-3.779	-3.772	-3.766	-3.759	-3.752	-300
-290	-3.752	-3.745	-3.737	-3.730	-3.723	-3.716	-3.709	-3.701	-3.694	-3.687	-3.679	-290
-280	-3.679	-3.672	-3.664	-3.657	-3.649	-3.642	-3.634	-3.627	-3.619	-3.611	-3.603	-280
-270	-3.603	-3.596	-3.588	-3.580	-3.572	-3.564	-3.556	-3.548	-3.540	-3.532	-3.524	-270
-260	-3.524	-3.516	-3.507	-3.499	-3.491	-3.483	-3.474	-3.466	-3.458	-3.449	-3.441	-260
-250	-3.441	-3.432	-3.424	-3.415	-3.406	-3.398	-3.389	-3.380	-3.372	-3.363	-3.354	-250
-3.354	-3.354	-3.345	-3.336	-3.327	-3.318	-3.309	-3.300	-3.291	-3.282	-3.273	-3.264	-240
-230	-3.264	-3.255	-3.245	-3.236	-3.227	-3.217	-3.208	-3.199	-3.189	-3.180	-3.170	-230
-220	-3.170	-3.161	-3.151	-3.142	-3.132	-3.122	-3.113	-3.103	-3.093	-3.083	-3.074	-220
-210	-3.074	-3.064	-3.054	-3.044	-3.034	-3.024	-3.014	-3.004	-2.994	-2.984	-2.974	-210
-200	-2.974	-2.964	-2.953	-2.943	-2.933	-2.923	-2.912	-2.902	-2.892	-2.881	-2.871	-200
-190	-2.871	-2.860	-2.850	-2.839	-2.829	-2.818	-2.807	-2.797	-2.786	-2.775	-2.765	-190
-180	-2.765	-2.754	-2.743	-2.732	-2.722	-2.711	-2.700	-2.689	-2.678	-2.667	-2.656	-180
-170	-2.656	-2.645	-2.634	-2.623	-2.612	-2.600	-2.589	-2.578	-2.567	-2.555	-2.544	-170
-160	-2.544	-2.533	-2.521	-2.510	-2.499	-2.487	-2.476	-2.464	-2.453	-2.441	-2.430	-160
-150	-2.430	-2.418	-2.407	-2.395	-2.383	-2.372	-2.360	-2.348	-2.336	-2.325	-2.313	-150
-140	-2.313	-2.301	-2.289	-2.277	-2.265	-2.253	-2.241	-2.229	-2.217	-2.205	-2.193	-140
-130	-2.193	-2.181	-2.169	-2.157	-2.145	-2.133	-2.120	-2.108	-2.096	-2.084	-2.071	-130
-120	-2.071	-2.059	-2.047	-2.034	-2.022	-2.009	-1.997	-1.985	-1.972	-1.960	-1.947	-120
-110	-1.947	-1.935	-1.922	-1.909	-1.897	-1.884	-1.871	-1.859	-1.846	-1.833	-1.821	-110
-100	-1.821	-1.808	-1.795	-1.782	-1.770	-1.757	-1.744	-1.731	-1.718	-1.705	-1.692	-100
-90	-1.692	-1.679	-1.666	-1.653	-1.640	-1.627	-1.614	-1.601	-1.588	-1.575	-1.562	-90
-80	-1.562	-1.549	-1.535	-1.522	-1.509	-1.496	-1.483	-1.469	-1.456	-1.443	-1.429	-80
-70	-1.429	-1.416	-1.403	-1.389	-1.376	-1.363	-1.349	-1.336	-1.322	-1.309	-1.295	-70

Table 8.1.10 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-60	-1.295	-1.282	-1.268	-1.255	-1.241	-1.228	-1.214	-1.201	-1.187	-1.173	-1.160	-60
-50	-1.160	-1.146	-1.132	-1.119	-1.105	-1.091	-1.078	-1.064	-1.050	-1.036	-1.023	-50
-40	-1.023	-1.009	-0.995	-0.981	-0.967	-0.953	-0.940	-0.926	-0.912	-0.898	-0.884	-40
-30	-0.884	-0.870	-0.856	-0.842	-0.828	-0.814	-0.800	-0.786	-0.772	-0.758	-0.744	-30
-20	-0.744	-0.730	-0.716	-0.702	-0.688	-0.674	-0.660	-0.646	-0.631	-0.617	-0.603	-20
-10	-0.603	-0.589	-0.575	-0.561	-0.546	-0.532	-0.518	-0.504	-0.489	-0.475	-0.461	-10
0	-0.461	-0.447	-0.432	-0.418	-0.404	-0.390	-0.375	-0.361	-0.347	-0.332	-0.318	0
10	-0.318	-0.303	-0.289	-0.275	-0.260	-0.246	-0.232	-0.217	-0.203	-0.188	-0.174	10
20	-0.174	-0.159	-0.145	-0.130	-0.116	-0.102	-0.087	-0.073	-0.058	-0.044	-0.029	20
30	-0.029	-0.015	0.000	0.014	0.029	0.043	0.058	0.072	0.087	0.101	0.115	30
40	0.115	0.130	0.144	0.159	0.173	0.188	0.202	0.217	0.232	0.246	0.261	40
50	0.261	0.275	0.290	0.304	0.319	0.334	0.348	0.363	0.378	0.392	0.407	50
60	0.407	0.422	0.436	0.451	0.466	0.481	0.495	0.510	0.525	0.540	0.554	60
70	0.554	0.569	0.584	0.599	0.614	0.629	0.643	0.658	0.673	0.688	0.703	70
80	0.703	0.718	0.733	0.748	0.763	0.778	0.793	0.808	0.823	0.838	0.853	80
90	0.853	0.868	0.883	0.898	0.913	0.928	0.943	0.958	0.973	0.988	1.003	90
100	1.003	1.019	1.034	1.049	1.064	1.079	1.095	1.110	1.125	1.140	1.156	100
110	1.156	1.171	1.186	1.201	1.217	1.232	1.247	1.263	1.278	1.293	1.309	110
120	1.309	1.324	1.339	1.355	1.370	1.386	1.401	1.417	1.432	1.448	1.463	120
130	1.463	1.479	1.494	1.510	1.525	1.541	1.556	1.572	1.587	1.603	1.619	130
140	1.619	1.634	1.650	1.666	1.681	1.697	1.713	1.728	1.744	1.760	1.775	140
150	1.775	1.791	1.807	1.823	1.838	1.854	1.870	1.886	1.902	1.917	1.933	150
160	1.933	1.949	1.965	1.981	1.997	2.013	2.029	2.045	2.060	2.076	2.092	160
170	2.092	2.108	2.124	2.140	2.156	2.172	2.188	2.204	2.221	2.237	2.253	170
180	2.253	2.269	2.285	2.301	2.317	2.333	2.349	2.366	2.382	2.398	2.414	180
190	2.414	2.430	2.447	2.463	2.479	2.495	2.512	2.528	2.544	2.561	2.577	190
200	2.577	2.593	2.610	2.626	2.642	2.659	2.675	2.691	2.708	2.724	2.741	200
210	2.741	2.757	2.774	2.790	2.807	2.823	2.840	2.856	2.873	2.889	2.906	210
220	2.906	2.922	2.939	2.955	2.972	2.989	3.005	3.022	3.038	3.055	3.072	220
230	3.072	3.088	3.105	3.122	3.139	3.155	3.172	3.189	3.205	3.222	3.239	230
240	3.239	3.256	3.273	3.289	3.306	3.323	3.340	3.357	3.374	3.391	3.407	240
250	3.407	3.424	3.441	3.458	3.475	3.492	3.509	3.526	3.543	3.560	3.577	250
260	3.577	3.594	3.611	3.628	3.645	3.662	3.679	3.696	3.713	3.730	3.748	260
270	3.748	3.765	3.782	3.799	3.816	3.833	3.850	3.868	3.885	3.902	3.919	270
280	3.919	3.936	3.954	3.971	3.988	4.005	4.023	4.040	4.057	4.075	4.092	280
290	4.092	4.109	4.127	4.144	4.161	4.179	4.196	4.214	4.231	4.248	4.266	290
300	4.266	4.283	4.301	4.318	4.336	4.353	4.371	4.388	4.406	4.423	4.441	300
310	4.441	4.458	4.476	4.493	4.511	4.529	4.546	4.564	4.581	4.599	4.617	310
320	4.617	4.634	4.652	4.670	4.687	4.705	4.723	4.740	4.758	4.776	4.794	320
330	4.794	4.811	4.829	4.847	4.865	4.882	4.900	4.918	4.936	4.954	4.971	330
340	4.971	4.989	5.007	5.025	5.043	5.061	5.079	5.097	5.114	5.132	5.150	340
350	5.150	5.168	5.186	5.204	5.222	5.240	5.258	5.276	5.294	5.312	5.330	350
360	5.330	5.348	5.366	5.384	5.402	5.420	5.439	5.457	5.475	5.493	5.511	360
370	5.511	5.529	5.547	5.565	5.584	5.602	5.620	5.638	5.656	5.674	5.693	370
380	5.693	5.711	5.729	5.747	5.766	5.784	5.802	5.820	5.839	5.857	5.875	380
390	5.875	5.894	5.912	5.930	5.949	5.967	5.985	6.004	6.022	6.040	6.059	390
400	6.059	6.077	6.096	6.114	6.132	6.151	6.169	6.188	6.206	6.225	6.243	400
410	6.243	6.262	6.280	6.299	6.317	6.336	6.354	6.373	6.391	6.410	6.429	410
420	6.429	6.447	6.466	6.484	6.503	6.521	6.540	6.559	6.577	6.596	6.615	420
430	6.615	6.633	6.652	6.671	6.689	6.708	6.727	6.745	6.764	6.783	6.802	430
440	6.802	6.820	6.839	6.858	6.877	6.895	6.914	6.933	6.952	6.971	6.989	440
450	6.989	7.008	7.027	7.046	7.065	7.084	7.102	7.121	7.140	7.159	7.178	450
460	7.178	7.197	7.216	7.235	7.254	7.273	7.291	7.310	7.329	7.348	7.367	460

Table 8.1.10 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
470	7.367	7.386	7.405	7.424	7.443	7.462	7.481	7.500	7.519	7.538	7.557	470
480	7.557	7.576	7.596	7.615	7.634	7.653	7.672	7.691	7.710	7.729	7.748	480
490	7.748	7.767	7.787	7.806	7.825	7.844	7.863	7.882	7.902	7.921	7.940	490
500	7.940	7.959	7.978	7.998	8.017	8.036	8.055	8.075	8.094	8.113	8.132	500
510	8.132	8.152	8.171	8.190	8.209	8.229	8.248	8.267	8.287	8.305	8.325	510
520	8.325	8.345	8.364	8.383	8.403	8.422	8.441	8.461	8.480	8.500	8.519	520
530	8.519	8.538	8.558	8.577	8.597	8.616	8.636	8.655	8.675	8.694	8.713	530
540	8.713	8.733	8.3752	8.772	8.791	8.811	8.830	8.850	8.870	8.889	8.909	540
550	8.909	8.928	8.948	8.967	8.987	9.006	9.026	9.046	9.065	9.085	9.104	550
560	9.104	9.124	9.144	9.163	9.183	9.202	9.2222	9.242	9.261	9.281	9.301	560
570	9.301	9.320	9.340	9.360	9.379	9.399	9.419	9.439	9.458	9.478	9.498	570
580	9.498	9.517	9.537	9.557	9.577	9.596	9.616	9.636	9.656	9.676	9.695	580
590	9.695	9.715	9.735	9.755	9.775	9.794	9.814	9.834	9.854	9.874	9.894	590
600	9.894	9.913	9.933	9.953	9.973	9.993	10.013	10.033	10.053	10.072	70.092	600
610	10.092	10.112	10.132	10.152	10.172	10.192	10.212	10.232	10.252	10.272	10.292	610
620	10.292	10.312	10.332	10.352	10.372	10.392	10.412	10.432	10.452	10.472	10.492	620
630	10.492	10.512	10.532	10.552	10.572	10.592	10.612	10.632	10.652	10.672	10.692	630
640	10.692	10.712	10.732	10.752	10.772	10.793	10.813	10.833	10.853	10.873	10.893	640
650	10.893	10.913	10.933	10.954	10.974	10.994	11.014	11.034	11.054	11.075	11.095	650
660	11.095	11.115	11.135	11.155	11.176	11.196	11.216	11.236	11.256	11.277	11.297	660
670	11.297	11.317	11.337	11.358	11.378	11.398	11.418	11.439	11.459	11.479	11.499	670
680	11.499	11.520	11.540	11560	11.581	11.601	11.621	11.642	11.662	11.682	11.703	680
690	11.703	11.723	11.743	11.764	11.784	11.804	11.825	11.845	11.865	11.886	11.906	690
700	11.906	11.926	11.947	11.967	11.988	12.008	12.028	12.049	12.069	12.090	12.110	700
710	12.110	12.131	12.151	12.171	12.192	12.212	12.233	12.253	12.274	12.294	12.315	710
720	12.315	12.335	12.356	12.376	12.397	12.417	12.438	12.458	12.479	12.499	12.520	720
730	12.520	12.540	12.561	12.581	12.602	12.622	12.643	12.663	12.684	12.705	12.725	730
740	12.725	12.746	12.766	12.787	12.807	12.828	12.849	12.869	12.890	12.910	12.931	740
750	12.931	12.952	12.972	12.993	13.013	13.034	13.055	13.075	13.096	13.117	13.137	750
760	13.137	13.158	13.179	13.199	13.220	13.241	13.261	13.282	13.303	13.323	13.344	760
770	13.344	13.365	13.385	13.406	13.427	13.447	13.468	13.489	13.510	13.530	13.551	770
780	13.551	13.572	13.593	13.613	13.634	13.655	13.676	13.696	13.717	13.738	13.759	780
790	13.759	13.779	13.800	13.821	13.842	13.863	13.883	13.904	13.925	13.946	13.967	790
800	13.967	13.987	14.008	14.029	14.050	14.071	14.091	14.112	14.133	14.154	14.175	800
810	14.175	14.196	14.217	14.237	14.258	14.279	14.300	14.321	14.342	14.363	14.384	810
820	14.384	14.404	14.425	14.446	14.467	14.488	14.509	14.530	14.551	14.572	14.593	820
830	14.593	14.614	14.634	14.655	14.676	14.697	14.718	14.739	14.760	14.781	14.802	830
840	14.802	14.823	14.844	14.865	14.886	14.907	14.928	14.949	14.970	14.991	15.012	840
850	15.012	15.033	15.054	15.075	15.096	15.117	15.138	15.159	15.180	15.201	15.222	850
860	15.222	15.243	15.264	15.285	15.306	15.327	15.348	15.369	15.390	15.411	15.432	860
870	15.432	15.453	15.475	15.496	15.517	15.538	15.559	15.580	15.601	15.622	15.643	870
880	15.643	15.664	15.685	15.707	15.728	15.749	15.770	15.791	15.812	15.833	15.854	880
890	15.854	15.875	15.897	15.918	15.939	15.960	15.981	16.002	16.023	16.045	16.066	890
900	16.066	16.087	16.108	16.129	16.150	16.172	16.193	16.214	16.235	16.256	16.278	900
910	16.278	16.299	16.320	16.341	16.362	16.383	16.405	16.426	16.447	16.468	16.490	910
920	16.490	16.511	16.532	16.553	16.574	16.596	16.617	16.638	16.659	16.681	16.702	920
930	16.702	16.723	16.744	16.766	16.787	16.808	16.829	16.851	16.872	16.893	16.915	930
940	16.915	16.936	16.957	16.978	17.000	17.021	17.042	17.064	17.085	17.106	17.127	940
950	17.127	17.149	17.170	17.191	17.213	17.234	17.255	17.277	17.298	17.319	17.341	950
960	17.341	17.362	17.383	17.405	17.426	17.447	17.469	17.490	17.511	17.533	17.554	960
970	17.554	17.575	17.597	17.618	17.639	17.661	17.682	17.704	17.725	17.746	17.768	970
980	17.768	17.789	17.811	17.832	17.853	17.875	17.896	17.917	17.939	17.960	17.982	980
990	17.982	18.003	18.025	18.046	18.067	18.089	18.110	18.132	18.153	18.174	18.196	990

Table 8.1.10 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1000	18.196	18.217	18.239	18.260	18.282	18.303	18.325	18.346	18.367	18.389	18.410	1000
1010	18.410	18.432	18.453	18.475	18.496	18.518	18.539	18.561	18.582	18.603	18.625	1010
1020	18.625	18.646	18.668	18.689	18.711	18.732	18.754	18.775	18.797	18.818	18.840	1020
1030	18.840	18.861	18.883	18.904	18.926	18.947	18.969	18.990	19.012	19.033	19.055	1030
1040	19.055	19.076	19.098	19.120	19.141	19.163	19.184	19.206	19.227	19.249	19.270	1040
1050	19.270	19.292	19.313	19.335	19.356	19.378	19.400	19.421	19.443	19.464	19.486	1050
1060	19.486	19.507	19.529	19.550	19.572	19.594	19.615	19.637	19.658	19.680	19.701	1060
1070	19.701	19.723	19.745	19.766	19.788	19.809	19.831	19.853	19.874	19.896	19.917	1070
1080	19.917	19.939	19.961	19.982	20.004	20.025	20.047	20.069	20.090	20.112	20.133	1080
1090	20.133	20.155	20.177	20.198	20.220	20.241	20.263	20.285	20.306	20.328	20.350	1090
1100	20.350	20.371	20.393	20.415	20.436	20.458	20.479	20.501	20.523	20.544	20.566	1100
1110	20.566	20.588	20.609	20.631	20.653	20.674	20.696	20.718	20.739	20.761	20.783	1110
1120	20.783	20.804	20.826	20.848	20.869	20.891	20.913	20.934	20.956	20.978	20.999	1120
1130	20.999	21.021	21.043	21.064	21.086	21.108	21.129	21.151	21.173	21.195	21.216	1130
1140	21.216	21.238	21.260	21.281	21.303	21.325	21.346	21.368	21.390	21.411	21.433	1140
1150	21.433	21.455	21.477	21.498	21.520	21.542	21.563	21.585	21.607	21.629	21.650	1150
1160	21.650	21.672	21.694	21.716	21.737	21.759	21.781	21.802	21.824	21.846	21.868	1160
1170	21.868	21.889	21.911	21.933	21.955	21.976	21.998	22.020	22.041	22.063	22.085	1170
1180	22.085	22.107	22.128	22.150	22.172	22.194	22.215	22.237	22.259	22.281	22.302	1180
1190	22.302	22.324	22.346	22.368	22.390	22.411	22.433	22.455	22.477	22.498	22.520	1190
1200	22.520	22.542	22.564	22.585	22.607	22.629	22.651	22.672	22.694	22.716	22.738	1200
1210	22.738	22.760	22.781	22.803	22.825	22.847	22.868	22.890	22.912	22.934	22.956	1210
1220	22.956	22.977	22.999	23.021	23.043	23.064	23.086	23.108	23.130	23.152	23.173	1220
1230	23.173	23.195	23.217	23.239	23.261	23.282	23.304	23.326	23.348	23.370	23.391	1230
1240	23.391	23.413	23.435	23.457	23.479	23.500	23.522	23.544	23.566	23.588	23.609	1240
1250	23.609	23.631	23.653	23.675	23.697	23.718	23.740	23.762	23.784	23.806	23.828	1250
1260	23.828	23.849	23.871	23.893	23.915	23.937	23.958	23.980	24.002	24.024	24.046	1260
1270	24.046	24.068	24.089	24.111	24.133	24.155	24.177	24.198	24.220	24.242	24.264	1270
1280	24.264	24.286	24.308	24.329	24.351	24.373	24.395	24.417	24.439	24.460	24.482	1280
1290	24.482	24.504	24.526	24.548	24.569	24.591	24.613	24.635	24.657	24.679	24.700	1290
1300	24.700	24.722	24.744	24.766	24.788	24.810	24.831	24.853	24.875	24.897	24.919	1300
1310	24.919	24.941	24.962	24.984	25.006	25.028	25.050	25.072	25.093	25.115	25.137	1310
1320	25.137	25.159	25.181	25.203	25.225	25.246	25.268	25.290	25.312	25.334	25.356	1320
1330	25.356	25.377	25.399	25.421	25.443	25.465	25.487	25.508	25.530	25.552	25.574	1330
1340	25.574	25.596	25.618	25.640	25.661	25.683	25.705	25.727	25.749	25.771	25.792	1340
1350	25.792	25.814	25.836	25.858	25.880	25.902	25.923	25.945	25.967	25.989	26.011	1350
1360	26.011	26.033	26.055	26.076	26.098	26.120	26.142	26.164	26.186	26.207	26.229	1360
1370	26.229	26.251	26.273	26.295	26.317	26.338	26.360	26.382	26.404	26.426	26.448	1370
1380	26.448	26.470	26.491	26.513	26.535	26.557	26.579	26.601	26.622	26.644	26.666	1380
1390	26.666	26.688	26.710	26.732	26.753	26.775	26.797	26.819	26.841	26.863	26.885	1390
1400	26.885	26.906	26.928	26.950	26.972	26.994	27.016	27.037	27.059	27.081	27.103	1400
1410	27.103	27.125	27.147	27.168	27.190	27.212	27.234	27.256	27.278	27.299	27.321	1410
1420	27.321	27.343	27.365	27.387	27.409	27.430	27.452	27.474	27.496	27.518	27.540	1420
1430	27.540	27.561	27.583	27.605	27.627	27.649	27.671	27.692	27.714	27.736	27.758	1430
1440	27.758	27.780	27.802	27.823	27.845	27.867	27.889	27.911	27.933	27.954	27.976	1440
1450	27.976	27.998	28.020	28.042	28.063	28.085	28.107	28.129	28.151	28.173	28.194	1450
1460	28.194	28.216	28.238	28.260	28.282	28.303	28.325	28.347	28.369	28.391	28.413	1460
1470	28.413	28.434	28.456	28.478	28.500	28.522	28.543	28.565	28.587	28.609	28.631	1470
1480	28.631	28.652	28.674	28.696	28.718	28.740	28.761	28.783	28.805	28.827	28.849	1480
1490	28.849	28.871	28.892	28.914	28.936	28.958	28.980	29.001	29.023	29.045	29.067	1490
1500	29.067	29.088	29.110	29.132	29.154	29.176	28.197	29.219	29.241	29.263	29.285	1500
1510	29.285	29.306	29.328	29.350	29.372	29.394	29.415	29.437	29.459	29.481	29.502	1510
1520	29.502	29.524	29.546	29.568	29.590	29.611	59.633	29.655	29.677	29.699	29.720	1520

Table 8.1.10 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1530	29.720	29.742	29.764	29.786	29.807	29.829	29.851	29.873	29.894	29.916	29.938	1530
1540	29.938	29.960	29.982	30.003	30.025	30.047	30.069	30.090	30.112	30.134	30.156	1540
1550	30.156	30.177	30.199	30.221	30.243	30.264	30.286	30.308	30.330	30.351	30.373	1550
1560	30.373	30.395	30.417	30.438	30.460	30.482	30.504	30.525	30.547	30.569	30.591	1560
1570	30.591	30.612	30.634	30.656	30.678	30.699	30.721	30.743	30.765	30.786	30.808	1570
1580	30.808	30.830	30.851	30.873	30.895	30.917	30.938	30.960	30.982	31.004	31.025	1580
1590	31.025	31.047	31.069	31.090	31.112	31.134	31.156	31.177	31.199	31.221	31.242	1590
1600	31.242	31.264	31.286	31.308	31.329	31.351	31.373	31.394	31.416	31.438	31.460	1600
1610	31.460	31.481	31.503	31.525	31.546	31.568	31.590	31.611	31.633	31.655	31.677	1610
1620	31.677	31.698	31.720	31.742	31.763	31.785	31.807	31.828	31.850	31.872	31.893	1620
1630	31.893	31.915	31.937	31.958	31.980	32.002	32.023	32.045	32.067	32.089	32.110	1630
1640	32.110	32.13	32.154	32.175	32.197	32.219	32.240	32.262	32.284	32.305	32.327	1640
1650	32.327	32.349	32.370	32.392	32.413	32.435	32.457	32.478	32.500	32.522	32.543	1650
1660	32.543	32.565	32.587	32.608	32.630	32.652	32.673	32.695	32.717	32.738	32.760	1660
1670	32.760	32.781	32.803	32.825	32.846	32.868	32.890	32.911	32.933	32.955	32.976	1670
1680	32.976	32.998	33.019	33.041	33.063	33.084	33.106	33.127	33.149	33.171	33.192	1680
1690	33.192	33.214	33.236	33.257	33.279	33.300	33.322	33.344	33.365	33.387	33.408	1690
1700	33.408	33.430	33.452	33.473	33.495	33.516	33.538	33.560	33.581	33.603	33.624	1700
1710	33.624	33.646	33.668	33.689	33.711	33.732	33.754	33.775	33.797	33.819	33.840	1710
1720	33.840	33.862	33.883	33.905	33.926	33.948	33.970	33.991	34.013	34.034	34.056	1720
1730	34.056	34.077	34.099	34.121	34.142	34.164	34.185	34.207	34.228	34.250	34.271	1730
1740	34.271	34.293	34.315	34.336	34.358	34.379	34.401	34.422	34.444	34.465	34.487	1740
1750	34.487	34.508	34.530	34.551	34.573	34.595	34.616	34.638	34.659	34.681	34.702	1750
1760	34.702	34.724	34.745	34.767	34.788	34.810	34.831	34.853	34.874	34.896	34.917	1760
1770	34.917	34.939	34.960	34.982	35.003	35.025	35.046	35.068	35.089	35.111	35.132	1770
1780	35.132	35.154	35.175	35.197	35.218	35.240	35.261	35.283	35.304	35.326	35.347	1780
1790	35.347	35.369	35.390	35.412	35.433	35.455	35.476	35.498	35.519	35.540	35.562	1790
1800	35.562	35.583	35.605	35.626	35.648	35.669	35.691	35.712	35.734	35.755	35.777	1800
1810	35.777	35.798	35.819	35.841	35.862	35.884	35.905	35.927	35.948	35.970	35.991	1810
1820	35.991	36.012	36.034	36.055	36.077	36.098	36.120	36.141	36.162	36.184	36.205	1820
1830	36.205	36.227	36.248	36.270	36.291	36.312	36.334	36.355	36.377	36.398	36.419	1830
1840	36.419	36.441	36.462	36.484	36.505	36.526	36.548	36.569	36.591	36.612	36.633	1840
1850	36.633	36.655	36.676	36.698	36.719	36.740	36.762	36.783	36.805	36.826	36.847	1850
1860	36.847	36.869	36.890	36.911	36.933	36.954	36.975	36.997	37.018	37.040	37.061	1860
1870	37.061	37.082	37.104	37.125	37.146	37.168	37.189	37.210	37.232	37.253	37.274	1870
1880	37.274	37.296	37.317	37.338	37.360	37.381	37.402	37.424	37.445	37.466	37.488	1880
1890	37.488	37.509	37.530	37.552	37.573	37.594	37.616	37.637	37.658	37.680	37.701	1890
1900	37.701	37.722	37.744	37.765	37.786	37.808	37.829	37.850	37.871	37.893	37.914	1900
1910	37.914	37.935	37.957	37.978	37.999	38.020	38.042	38.063	38.084	38.106	38.127	1910
1920	38.127	38.148	38.169	38.191	38.212	38.233	38.254	38.276	38.297	38.318	38.340	1920
1930	38.340	38.361	38.382	38.403	38.425	38.446	38.467	38.488	38.510	38.531	38.552	1930
1940	38.552	38.573	38.594	38.616	38.637	38.658	38.679	38.701	38.722	38.743	38.764	1940
1950	38.764	38.786	38.807	38.828	38.849	38.870	38.892	38.913	38.934	38.955	38.976	1950
1960	38.976	38.998	39.019	39.040	39.061	39.082	39.104	39.125	39.146	39.167	39.188	1960
1970	39.188	39.210	39.231	39.252	39.273	39.294	39.315	39.337	39.358	39.379	39.400	1970
1980	39.400	39.421	39.442	39.464	39.485	39.506	39.527	39.548	39.569	39.591	39.612	1980
1990	39.612	39.633	39.654	39.675	39.696	39.717	39.739	39.760	39.781	39.802	39.823	1990
2000	39.823	39.844	39.865	39.886	39.908	39.929	39.950	39.971	39.992	40.013	40.034	2000
2010	40.034	40.055	40.076	40.097	40.119	40.140	40.161	40.182	40.203	40.224	40.245	2010
2020	40.245	40.266	40.287	40.308	40.329	40.351	40.372	40.393	40.414	40.435	40.456	2020
2030	40.456	40.477	40.498	40.519	40.540	40.561	40.582	40.603	40.624	40.645	40.666	2030
2040	40.666	40.687	40.708	40.729	40.750	40.772	40.793	40.814	40.835	40.856	40.877	2040
2050	40.877	40.898	40.919	40.940	40.961	40.982	41.003	41.024	41.045	41.066	41.087	2050

Table 8.1.10 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2060	41.087	41.108	41.129	41.150	41.171	41.192	41.213	41.234	41.255	41.276	41.297	2060
2070	41.297	41.318	41.338	41.359	41.380	41.401	41.422	41.443	41.464	41.485	41.506	2070
2080	41.506	41.527	41.548	41.569	41.590	41.611	41.632	41.653	41.674	41.695	41.716	2080
2090	41.716	41.736	41.757	41.778	41.799	41.820	41.841	41.862	41.883	41.904	41.925	2090
2100	41.925	41.946	41.966	41.987	42.008	42.029	42.050	42.071	42.092	42.113	42.134	2100
2110	42.134	42.154	42.175	42.196	42.217	42.238	42.259	42.280	42.300	42.321	42.342	2110
2120	42.342	42.363	42.384	42.405	42.425	42.446	42.467	42.488	42.509	42.530	42.550	2120
2130	42.550	42.571	42.592	42.613	42.634	42.655	42.675	42.696	42.717	42.738	42.759	2130
2140	42.759	42.779	42.800	42.821	42.842	42.862	42.883	42.904	42.925	42.946	42.966	2140
2150	42.966	42.987	43.008	43.029	43.049	43.070	43.091	43.112	43.132	43.153	43.174	2150
2160	43.174	43.195	43.215	43.236	43.257	43.278	43.298	43.319	43.340	43.360	43.381	2160
2170	43.381	43.402	43.423	43.443	43.464	43.485	43.505	43.526	43.547	43.567	43.588	2170
2180	43.588	43.609	43.629	43.650	43.671	43.692	43.712	43.733	43.754	43.774	43.795	2180
2190	43.795	43.815	43.836	43.857	43.877	43.898	43.919	43.939	43.960	43.981	44.001	2190
2200	44.001	44.022	44.042	44.063	44.084	44.104	44.125	44.146	44.166	44.187	44.207	2200
2210	44.207	44.228	44.248	44.269	44.290	44.310	44.331	44.351	44.372	44.393	44.413	2210
2220	44.413	44.434	44.454	44.475	44.495	44.516	44.536	44.557	44.577	44.598	44.619	2220
2230	44.619	44.639	44.660	44.680	44.701	44.721	44.742	44.762	44.783	44.803	44.824	2230
2240	44.824	44.844	44.865	44.885	44.906	44.926	44.947	44.967	44.988	45.008	45.029	2240
2250	45.029	45.049	45.069	45.090	45.110	45.131	45.151	45.172	45.192	45.213	45.233	2250
2260	45.233	45.254	45.274	45.294	45.315	45.335	45.356	45.376	45.396	45.417	45.437	2260
2270	45.437	45.458	45.478	45.498	45.519	45.539	45.560	45.580	45.600	45.621	45.641	2270
2280	45.641	45.662	45.682	45.702	45.723	45.743	45.763	45.784	45.804	45.824	45.845	2280
2290	45.845	45.865	45.885	45.906	45.926	45.946	45.967	45.987	46.007	46.028	46.048	2290
2300	46.048	46.068	46.089	46.109	46.129	46.149	46.170	46.190	46.210	46.231	46.251	2300
2310	46.251	46.271	46.291	46.312	46.332	46.352	46.372	46.393	46.413	46.433	46.453	2310
2320	46.453	46.474	46.494	46.514	46.534	46.555	46.575	46.595	46.615	46.636	46.656	2320
2330	46.656	46.676	46.696	46.716	46.737	46.757	46.777	46.797	46.817	46.838	46.858	2330
2340	46.858	46.878	46.898	46.918	46.938	46.959	46.979	46.999	47.019	47.039	47.059	2340
2350	47.059	47.079	47.100	47.120	47.140	47.160	47.180	47.200	47.220	47.241	47.261	2350
2360	47.261	47.281	47.301	47.321	47.341	47.361	47.381	47.401	47.421	47.442	47.462	2360
2370	47.462	47.482	47.502									2370

T/C Type R - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.11 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-50	-0.226	-0.223	-0.219	-0.215	-0.211	-0.207	-0.204	-0.200	-0.196	-0.192	-0.188	-50
-40	-0.188	-0.184	-0.180	-0.175	-0.171	-0.167	-0.163	-0.158	-0.154	-0.150	-0.145	-40
-30	-0.145	-0.141	-0.137	-0.132	-0.128	-0.123	-0.119	-0.114	-0.109	-0.105	-0.100	-30
-20	-0.100	-0.095	-0.091	-0.086	-0.081	-0.076	-0.071	-0.066	-0.061	-0.056	-0.051	-20
-10	-0.051	-0.046	-0.041	-0.036	-0.031	-0.026	-0.021	-0.016	-0.011	-0.005	0.000	-10
0	0.000	0.005	0.011	0.016	0.021	0.027	0.032	0.038	0.043	0.049	0.054	0
10	0.054	0.060	0.065	0.071	0.077	0.082	0.088	0.094	0.100	0.105	0.111	10
20	0.111	0.117	0.123	0.129	0.135	0.141	0.147	0.152	0.158	0.165	0.171	20
30	0.171	0.177	0.183	0.189	0.195	0.201	0.207	0.214	0.220	0.226	0.232	30
40	0.232	0.239	0.245	0.251	0.258	0.264	0.271	0.277	0.283	0.290	0.296	40
50	0.296	0.303	0.310	0.316	0.323	0.329	0.336	0.343	0.349	0.356	0.363	50
60	0.363	0.369	0.376	0.383	0.390	0.397	0.403	0.410	0.417	0.424	0.431	60

Table 8.1.11 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
70	0.431	0.438	0.445	0.452	0.459	0.466	0.473	0.480	0.487	0.494	0.501	70
80	0.501	0.508	0.515	0.523	0.530	0.537	0.544	0.552	0.559	0.566	0.573	80
90	0.573	0.581	0.588	0.595	0.603	0.610	0.617	0.625	0.632	0.640	0.647	90
100	0.647	0.655	0.662	0.670	0.677	0.685	0.692	0.700	0.08	0.715	0.723	100
110	0.723	0.730	0.738	0.746	0.754	0.761	0.769	0.777	0.784	0.792	0.800	110
120	0.800	0.808	0.816	0.824	0.831	0.839	0.847	0.855	0.863	0.871	0.879	120
130	0.879	0.887	0.895	0.903	0.911	0.919	0.927	0.935	0.943	0.951	0.959	130
140	0.959	0.967	0.975	0.983	0.992	1.000	1.008	1.016	1.024	1.032	1.041	140
150	1.041	1.049	1.057	1.065	1.074	1.082	1.090	1.099	1.107	1.115	1.124	150
160	1.124	1.132	1.140	1.149	1.157	1.166	1.174	1.183	1.191	1.200	1.208	160
170	1.208	1.217	1.225	1.234	1.242	1.251	1.259	1.268	1.276	1.285	1.294	170
180	1.294	1.302	1.311	1.319	1.328	1.337	1.345	1.354	1.363	1.372	1.380	180
190	1.380	1.389	1.398	1.407	1.415	1.424	1.433	1.442	1.450	1.459	1.468	190
200	1.468	1.477	1.486	1.495	1.504	1.512	1.521	1.530	1.539	1.548	1.557	200
210	1.557	1.566	1.575	1.584	1.593	1.602	1.611	1.620	1.629	1.638	1.647	210
220	1.647	1.656	1.665	1.674	1.683	1.692	1.702	1.711	1.720	1.729	1.738	220
230	1.738	1.747	1.756	1.766	1.775	1.784	1.793	1.802	1.812	1.821	1.830	230
240	1.830	1.839	1.849	1.858	1.867	1.876	1.886	1.895	1.904	1.914	1.923	240
250	1.923	1.932	1.942	1.951	1.960	1.970	1.979	1.988	1.998	2.007	2.017	250
260	2.017	2.026	2.036	2.045	2.054	2.064	2.073	2.083	2.092	2.102	2.111	260
270	2.111	2.121	2.130	2.140	2.149	2.159	2.169	2.178	2.188	2.197	2.207	270
280	2.207	2.216	2.226	2.236	2.245	2.255	2.264	2.274	2.284	2.293	2.303	280
290	2.303	2.313	2.322	2.332	2.342	2.351	2.361	2.371	2.381	2.390	2.400	290
300	2.400	2.410	2.420	2.429	2.439	2.449	2.459	2.468	2.478	2.488	2.498	300
310	2.498	2.508	2.517	2.527	2.37	2.547	2.557	2.567	2.577	2.586	2.596	310
320	2.596	2.606	2.616	2.626	2.636	2.646	2.656	2.666	2.676	2.685	2.695	320
330	2.695	2.705	2.715	2.725	2.735	2.745	2.755	2.765	2.775	2.785	2.795	330
340	2.795	2.805	2.815	2.825	2.835	2.845	2.855	2.866	2.876	2.886	2.896	340
350	2.896	2.906	2.916	2.926	2.936	2.946	2.956	2.966	2.977	2.987	2.997	350
360	2.997	3.007	3.017	3.027	3.037	3.048	3.058	3.068	3.078	3.088	3.099	360
370	3.099	3.109	3.119	3.129	3.139	3.150	3.160	3.170	3.180	3.191	3.201	370
380	3.201	3.211	3.221	3.232	3.242	3.252	3.263	3.273	3.283	3.293	3.304	380
390	3.304	3.314	3.324	3.335	3.345	3.355	3.366	3.376	3.386	3.397	3.407	390
400	3.407	3.418	3.428	3.438	3.449	3.459	3.470	3.480	3.490	3.501	3.511	400
410	3.511	3.522	3.532	3.543	3.553	3.563	3.574	3.584	3.595	3.605	3.616	410
420	3.616	3.626	3.637	3.647	3.658	3.668	3.679	3.689	3.700	3.710	3.721	420
430	3.721	3.731	3.742	3.752	3.763	3.774	3.784	3.795	3.805	3.816	3.826	430
440	3.826	3.837	3.848	3.858	3.869	3.879	3.890	3.901	3.911	3.922	3.933	440
450	3.933	3.943	3.954	3.964	3.975	3.986	3.996	4.007	4.018	4.028	4.039	450
460	4.039	4.050	4.061	4.071	4.082	4.093	4.103	4.114	4.125	4.136	4.146	460
470	4.146	4.157	4.168	4.178	4.189	4.200	5.211	5.222	4.232	4.243	4.254	470
480	4.254	4.265	4.275	4.286	4.297	4.308	4.319	4.329	4.340	4.351	4.362	480
490	4.362	4.373	4.384	4.394	4.405	4.416	4.427	4.438	4.449	4.460	4.471	490
500	4.471	4.481	4.492	4.503	4.514	4.525	4.536	4.547	4.558	4.569	4.580	500
510	4.580	4.591	4.601	4.612	4.623	4.634	4.645	4.656	4.667	4.678	4.689	510
520	4.689	4.700	4.711	4.722	4.733	4.744	4.755	4.766	4.777	4.788	4.799	520
530	4.799	4.810	4.821	4.832	4.843	4.854	4.865	4.876	4.888	4.899	4.910	530
540	4.910	4.921	4.932	4.943	4.954	4.965	4.976	4.987	4.998	5.009	5.021	540
550	5.021	5.032	5.043	5.054	5.065	5.076	5.087	5.099	5.110	5.121	5.132	550
560	5.132	5.143	5.154	5.166	5.177	5.188	5.199	5.210	5.221	5.233	5.244	560
570	5.244	5.255	5.266	5.276	5.289	5.300	5.311	5.322	5.334	5.345	5.356	570
580	5.356	5.368	5.379	5.390	5.401	5.413	5.424	5.435	5.446	5.458	5.469	580
590	5.469	5.480	5.492	5.503	5.514	5.526	5.537	5.548	5.560	5.571	5.582	590

Table 8.1.11 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
600	5.582	5.594	5.605	5.616	5.628	5.639	5.650	5.662	5.673	5.685	5.696	600
610	5.696	5.707	5.719	5.730	5.742	5.753	5.764	5.776	5.787	5.799	5.810	610
620	5.810	5.821	5.833	5.844	5.856	5.867	5.879	5.890	5.902	5.913	5.925	620
630	5.925	5.936	5.948	5.959	5.971	5.982	5.994	6.005	6.017	6.028	6.040	630
640	6.040	6.051	6.063	6.074	6.086	6.098	6.109	6.121	6.132	6.144	6.155	640
650	6.155	6.167	6.179	6.190	6.202	6.213	6.225	6.237	6.248	6.260	6.272	650
660	6.272	6.283	6.295	6.307	6.318	6.330	6.342	6.353	6.365	6.377	6.388	660
670	6.388	6.400	6.412	6.423	6.435	6.447	6.458	6.470	6.482	6.494	6.505	670
680	6.505	6.517	6.529	6.541	6.552	6.564	6.576	6.588	6.599	6.611	6.623	680
690	6.623	6.635	6.647	6.658	6.670	6.682	6.694	6.706	6.718	6.729	6.741	690
700	6.741	6.753	6.765	6.777	6.789	6.800	6.812	6.824	6.836	6.848	6.860	700
710	6.860	6.872	6.884	6.895	6.907	6.919	6.931	6.943	6.955	6.967	6.979	710
720	6.979	6.991	7.003	7.015	7.027	7.039	7.051	7.063	7.074	7.086	7.098	720
730	7.098	7.110	7.122	7.134	7.146	7.158	7.170	7.182	7.194	7.206	7.218	730
740	7.218	7.231	7.243	7.255	7.267	7.279	7.291	7.303	7.315	7.327	7.339	740
750	7.339	7.351	7.363	7.375	7.387	7.399	7.412	7.424	7.436	7.448	7.460	750
760	7.460	7.472	7.484	7.496	7.509	7.521	7.533	7.545	7.557	7.569	7.582	760
770	7.582	7.594	7.606	7.618	7.630	7.642	7.655	7.667	7.679	7.691	7.703	770
780	7.703	7.716	7.728	7.740	7.752	7.765	7.777	7.789	7.801	7.814	7.826	780
790	7.826	7.838	7.850	7.863	7.875	7.887	7.900	7.912	7.924	7.937	7.949	790
800	7.949	7.961	7.973	7.986	7.998	8.010	8.023	8.035	8.047	8.060	8.072	800
810	8.072	8.085	8.097	8.109	8.122	8.134	8.146	8.159	8.171	8.184	8.196	810
820	8.196	8.208	8.221	8.233	8.246	8.258	8.271	8.283	8.295	8.308	8.320	820
830	8.320	8.333	8.345	8.358	8.370	8.383	8.395	8.408	8.420	8.433	8.445	830
840	8.445	8.458	8.470	8.483	8.495	8.508	8.520	8.533	8.545	8.558	8.570	840
850	8.570	8.583	8.595	8.608	8.621	8.633	8.646	8.658	8.671	8.683	8.696	850
860	8.696	8.709	8.721	8.734	8.746	8.759	8.772	8.784	8.797	8.810	8.822	860
870	8.822	8.835	8.847	8.860	8.873	8.885	8.898	8.911	8.923	8.936	8.949	870
880	8.949	8.961	8.974	8.987	9.000	9.012	9.025	9.038	9.050	9.063	9.076	880
890	9.076	9.089	9.101	9.114	9.127	9.140	9.152	9.165	9.178	9.191	9.203	890
900	9.203	9.216	9.229	9.242	9.254	9.267	9.280	9.293	9.306	9.319	9.331	900
910	9.331	9.344	9.357	9.370	9.383	9.395	9.408	9.421	9.434	9.447	9.460	910
920	9.460	9.473	9.485	9.498	9.511	9.524	9.537	9.550	9.563	9.576	9.589	920
930	9.589	9.602	9.614	9.627	9.640	9.653	9.666	9.679	9.692	9.705	9.718	930
940	9.718	9.731	9.744	9.757	9.770	9.783	9.796	9.809	9.822	9.835	9.848	940
950	9.848	9.861	9.874	9.887	9.900	9.913	9.926	9.939	9.952	9.965	9.978	950
960	9.978	9.991	10.004	10.017	10.030	10.043	10.056	10.069	10.082	10.095	10.109	960
970	10.109	10.122	10.135	10.148	10.161	10.174	10.187	10.200	10.213	10.227	10.240	970
980	10.240	10.253	10.266	10.279	10.292	10.305	10.319	10.332	10.345	10.358	10.371	980
990	10.371	10.384	10.398	10.411	10.424	10.437	10.450	10.464	10.477	10.490	10.503	990
1000	10.503	10.516	10.530	10.543	10.556	10.569	10.583	10.596	10.609	10.622	10.636	1000
1010	10.636	10.649	10.662	10.675	10.689	10.702	10.715	10.729	10.742	10.755	10.768	1010
1020	10.768	10.782	10.795	10.808	10.822	10.835	10.848	10.862	10.875	10.888	10.902	1020
1030	10.902	10.915	10.928	10.942	10.955	10.968	10.982	10.995	11.009	11.022	11.035	1030
1040	11.035	11.049	11.062	11.076	11.089	11.102	11.116	11.129	11.143	11.156	11.170	1040
1050	11.170	11.183	11.196	11.210	11.223	11.237	11.250	11.264	11.277	11.291	11.304	1050
1060	11.304	11.318	11.331	11.345	11.358	11.372	11.385	11.399	11.412	11.426	11.439	1060
1070	11.439	11.453	11.466	11.480	11.493	11.507	11.520	11.534	11.547	11.561	11.574	1070
1080	11.574	11.588	11.602	11.615	11.629	11.642	11.656	11.669	11.683	11.697	11.710	1080
1090	11.710	11.724	11.737	11.751	11.765	11.778	11.792	11.805	11.819	11.833	11.846	1090
1100	11.846	11.860	11.874	11.887	11.901	11.914	11.928	11.942	11.955	11.969	11.983	1100
1110	11.983	11.996	12.010	12.024	12.037	12.051	12.065	12.078	12.092	12.106	12.119	1110
1120	12.119	12.133	12.147	12.161	12.174	12.188	12.202	12.215	12.229	12.243	12.257	1120

Table 8.1.11 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1130	12.257	12.270	12.284	12.298	12.311	12.325	12.339	12.353	12.366	12.380	12.394	1130
1140	12.394	12.408	12.421	12.435	12.449	12.463	12.476	12.490	12.504	12.518	12.532	1140
1150	12.532	12.545	12.559	12.573	12.587	12.600	12.614	12.628	12.642	12.656	12.669	1150
1160	12.669	12.683	12.697	12.711	12.725	12.739	12.752	12.766	12.780	12.794	12.808	1160
1170	12.808	12.822	12.835	12.849	12.863	12.877	12.891	12.905	12.918	12.932	12.946	1170
1180	12.946	12.960	12.974	12.988	13.002	13.016	13.029	13.043	13.057	13.071	13.085	1180
1190	13.085	13.099	13.113	13.127	13.140	13.154	13.168	13.182	13.196	13.210	13.224	1190
1200	13.224	13.238	13.252	13.266	13.280	13.293	13.307	13.321	13.335	13.349	13.363	1200
1210	13.363	13.377	13.391	13.405	13.419	13.433	13.447	13.461	13.475	13.489	13.502	1210
1220	13.502	13.516	13.530	13.544	13.558	13.572	13.586	13.600	13.614	13.628	13.642	1220
1230	13.642	13.656	13.670	13.684	13.698	13.712	13.726	13.740	13.754	13.768	13.782	1230
1240	13.782	13.796	13.810	13.824	13.838	13.852	13.866	13.880	13.894	13.908	13.922	1240
1250	13.922	13.936	13.950	13.964	13.978	13.992	14.006	14.020	14.034	14.048	14.062	1250
1260	14.062	14.076	14.090	14.104	14.118	14.132	14.146	14.160	14.174	14.188	14.202	1260
1270	14.202	14.216	14.230	14.244	14.258	14.272	14.286	14.301	14.315	14.329	14.343	1270
1280	14.343	14.357	14.371	14.385	14.399	14.413	14.427	14.441	14.455	14.469	14.483	1280
1290	14.483	14.497	14.511	14.525	14.539	14.554	14.568	14.582	14.596	14.610	14.624	1290
1300	14.624	14.638	14.652	14.666	14.680	14.694	14.708	14.722	14.737	14.751	14.765	1300
1310	14.765	14.779	14.793	14.807	14.821	14.835	14.849	14.863	14.877	14.891	14.906	1310
1320	14.906	14.920	14.934	14.948	14.962	14.976	14.990	15.004	15.018	15.032	15.047	1320
1330	15.047	15.061	15.075	15.089	15.103	15.117	15.131	15.145	15.159	15.173	15.188	1330
1340	15.188	15.202	15.216	15.230	15.244	15.258	15.272	15.286	15.300	15.315	15.329	1340
1350	15.329	15.343	15.357	15.371	15.385	15.399	15.413	15.427	15.442	15.456	15.470	1350
1360	15.470	15.484	15.498	15.512	15.526	15.540	15.555	15.569	15.583	15.597	15.611	1360
1370	15.611	15.625	15.639	15.653	15.667	15.682	15.696	15.710	15.724	15.738	15.752	1370
1380	15.752	15.766	15.780	15.795	15.809	15.823	15.837	15.851	15.865	15.879	15.893	1380
1390	15.893	15.908	15.922	15.936	15.950	15.964	15.978	15.992	16.006	16.021	16.035	1390
1400	16.035	16.049	16.063	16.077	16.091	16.105	16.119	16.134	16.148	16.162	16.176	1400
1410	16.176	16.190	16.204	16.218	16.232	16.247	16.261	16.275	16.289	16.303	16.317	1410
1420	16.317	16.331	16.345	16.360	16.374	16.388	16.402	16.416	16.430	16.444	16.458	1420
1430	16.458	16.472	16.487	16.501	16.515	16.529	16.543	16.557	16.571	16.585	16.599	1430
1440	16.599	16.614	16.628	16.642	16.656	16.670	16.684	16.698	16.712	16.726	16.741	1440
1450	16.741	16.755	16.769	16.783	16.797	16.811	16.825	16.839	16.853	16.867	16.882	1450
1460	16.882	16.896	16.910	16.924	16.938	16.952	16.966	16.980	16.994	17.008	17.022	1460
1470	17.022	17.037	17.051	17.065	17.079	17.093	17.107	17.121	17.135	17.149	17.163	1470
1480	17.163	17.177	17.192	17.206	17.220	17.234	17.248	17.262	17.276	17.290	17.304	1480
1490	17.304	17.318	17.332	17.346	17.360	17.374	17.388	17.403	17.417	17.431	17.445	1490
1500	17.445	17.459	17.473	17.487	17.501	17.515	17.529	17.543	17.557	17.571	17.585	1500
1510	17.585	17.599	17.613	17.627	17.641	17.655	17.669	17.684	17.698	17.712	17.726	1510
1520	17.726	17.740	17.754	17.768	17.782	17.796	17.810	17.824	17.838	17.852	17.866	1520
1530	17.866	17.880	17.894	17.908	17.922	17.936	17.950	17.964	17.978	17.992	18.006	1530
1540	18.006	18.020	18.034	18.048	18.062	18.076	18.090	18.104	18.118	18.132	18.146	1540
1550	18.146	18.160	18.174	18.188	18.202	18.216	18.230	18.244	18.258	18.272	18.286	1550
1560	18.286	18.299	18.313	18.327	18.341	18.355	18.369	18.383	18.397	18.411	18.425	1560
1570	18.425	18.439	18.453	18.467	18.481	18.495	18.509	18.523	18.537	18.550	18.564	1570
1580	18.564	18.578	18.592	18.606	18.620	18.634	18.648	18.662	18.676	18.690	18.703	1580
1590	18.703	18.717	18.731	18.745	18.759	18.773	18.787	18.801	18.815	18.828	18.842	1590
1600	18.842	18.856	18.870	18.884	18.898	18.912	18.926	18.939	18.953	18.967	18.981	1600
1610	18.981	18.995	19.009	19.023	19.036	19.050	19.064	19.078	19.092	19.106	19.119	1610
1620	19.119	19.133	19.147	19.161	19.175	19.188	19.202	19.216	19.230	19.244	19.257	1620
1630	19.257	19.271	19.285	19.299	19.313	19.326	19.340	19.354	19.368	19.382	19.395	1630
1640	19.395	19.409	19.423	19.437	19.450	19.464	19.478	19.492	19.505	19.519	19.533	1640
1650	19.533	19.547	19.560	19.574	19.588	19.602	19.615	19.629	19.643	19.656	19.670	1650

Table 8.1.11 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1660	19.670	19.684	19.698	19.711	19.725	19.739	19.752	19.766	19.780	19.793	19.807	1660
1670	19.807	19.821	19.834	19.848	19.862	19.875	19.889	19.903	19.916	19.930	19.944	1670
1680	19.944	19.957	19.971	19.985	19.998	20.012	20.025	20.039	20.053	20.066	20.080	1680
1690	20.080	20.093	20.107	20.120	20.134	20.148	20.161	20.175	20.188	20.202	20.215	1690
1700	20.215	20.229	20.242	20.256	20.269	20.283	20.296	20.309	20.323	20.336	20.350	1700
1710	20.350	20.363	20.377	20.390	20.403	20.417	20.430	20.443	20.457	20.470	20.483	1710
1720	20.483	20.497	20.510	20.523	20.537	20.550	20.563	20.576	20.590	20.603	20.616	1720
1730	20.616	20.629	20.642	20.656	20.669	20.682	20.695	20.708	20.721	20.734	20.748	1730
1740	20.748	20.761	20.774	20.787	20.800	20.813	20.826	20.839	20.852	20.865	20.878	1740
1750	20.878	20.891	20.904	20.916	20.929	20.942	20.955	20.968	20.981	20.994	21.006	1750
1760	21.006	21.019	21.032	21.045	21.057	21.070	21.083	21.096	21.108			1760

T/C Type R - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.12 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-60			-0.226	-0.224	-0.222	-0.220	-0.218	-0.216	-0.214	-0.212	-0.210	-60
-50	-0.210	-0.207	-0.205	-0.203	-0.201	-0.199	-0.197	-0.194	-0.192	-0.190	-0.188	-50
-40	-0.188	-0.185	-0.183	-0.181	-0.179	-0.176	-0.174	-0.172	-0.169	-0.167	-0.165	-40
-30	-0.165	-0.162	-0.160	-0.158	-0.155	-0.153	-0.150	-0.148	-0.145	-0.143	-0.141	-30
-20	-0.141	-0.138	-0.136	-0.133	-0.131	-0.128	-0.126	-0.123	-0.121	-0.118	-0.116	-20
-10	-0.116	-0.113	-0.110	-0.108	-0.105	-0.103	-0.100	-0.097	-0.095	-0.092	-0.089	-10
0	-0.089	-0.087	-0.084	-0.082	-0.079	-0.076	-0.073	-0.071	-0.068	-0.065	-0.063	0
10	-0.063	-0.060	-0.057	-0.054	-0.051	-0.049	-0.046	-0.043	-0.040	-0.037	-0.035	10
20	-0.035	-0.032	-0.029	-0.026	-0.023	-0.020	-0.017	-0.015	-0.012	-0.009	-0.006	20
30	-0.006	-0.003	0.000	0.003	0.006	0.009	0.012	0.015	0.018	0.021	0.024	30
40	0.024	0.027	0.030	0.033	0.036	0.039	0.042	0.045	0.048	0.051	0.054	40
50	0.054	0.057	0.060	0.064	0.067	0.070	0.073	0.076	0.079	0.082	0.086	50
60	0.086	0.089	0.092	0.095	0.098	0.101	0.105	0.108	0.111	0.114	0.118	60
70	0.118	0.121	0.124	0.127	0.131	0.134	0.137	0.141	0.144	0.147	0.150	70
80	0.150	0.154	0.157	0.161	0.164	0.167	0.171	0.174	0.177	0.181	0.184	80
90	0.184	0.188	0.191	0.194	0.198	0.201	0.205	0.208	0.212	0.215	0.218	90
100	0.218	0.222	0.225	0.229	0.232	0.236	0.239	0.243	0.246	0.250	0.253	100
110	0.253	0.257	0.261	0.264	0.268	0.271	0.275	0.278	0.282	0.286	0.289	110
120	0.289	0.293	0.296	0.300	0.304	0.307	0.311	0.315	0.318	0.322	0.326	120
130	0.326	0.329	0.333	0.337	0.340	0.344	0.348	0.351	0.355	0.359	0.363	130
140	0.363	0.366	0.370	0.374	0.378	0.381	0.385	0.389	0.393	0.397	0.400	140
150	0.400	0.404	0.408	0.412	0.416	0.419	0.423	0.427	0.431	0.435	0.439	150
160	0.439	0.443	0.446	0.450	0.454	0.458	0.462	0.466	0.470	0.474	0.478	160
170	0.478	0.482	0.475	0.489	0.493	0.497	0.501	0.505	0.509	0.513	0.517	170
180	0.517	0.521	0.525	0.529	0.533	0.537	0.541	0.545	0.549	0.553	0.557	180
190	0.557	0.561	0.565	0.569	0.573	0.577	0.581	0.586	0.590	0.594	0.598	190
200	0.598	0.602	0.606	0.610	0.614	0.618	0.622	0.627	0.631	0.635	0.639	200
210	0.639	0.643	0.647	0.651	0.656	0.660	0.664	0.668	0.672	0.676	0.681	210
220	0.681	0.685	0.689	0.693	0.697	0.702	0.706	0.710	0.714	0.719	0.723	220
230	0.723	0.727	0.731	0.736	0.740	0.744	0.748	0.753	0.757	0.761	0.766	230
240	0.766	0.770	0.774	0.778	0.783	0.787	0.791	0.796	0.800	0.804	0.809	240
250	0.809	0.813	0.817	0.822	0.826	0.830	0.835	0.839	0.844	0.848	0.852	250
260	0.852	0.857	0.861	0.866	0.870	0.874	0.879	0.883	0.888	0.892	0.897	260

Table 8.1.12 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
270	0.897	0.901	0.905	0.910	0.914	0.919	0.923	0.928	0.932	0.937	0.941	270
280	0.941	0.946	0.950	0.955	0.959	0.964	0.968	0.973	0.977	0.982	0.986	280
290	0.986	0.991	0.995	1.000	1.004	1.009	1.013	1.018	1.022	1.027	1.032	290
300	1.032	1.036	1.041	1.045	1.050	1.054	1.059	1.064	1.068	1.073	1.077	300
310	1.077	1.082	1.087	1.091	1.096	1.101	1.105	1.110	1.114	1.119	1.124	310
320	1.124	1.128	1.133	1.138	1.142	1.147	1.152	1.156	1.161	1.166	1.170	320
330	1.170	1.175	1.180	1.184	1.189	1.194	1.199	1.203	1.208	1.213	1.217	330
340	1.217	1.222	1.227	1.232	1.236	1.241	1.246	1.251	1.255	1.260	1.265	340
350	1.265	1.270	1.274	1.279	1.284	1.289	1.294	1.298	1.303	1.308	1.313	350
360	1.313	1.318	1.322	1.327	1.332	1.337	1.342	1.346	1.351	1.356	1.361	360
370	1.361	1.366	1.371	1.375	1.380	1.385	1.390	1.395	1.400	1.405	1.409	370
380	1.409	1.414	1.419	1.424	1.429	1.434	1.439	1.444	1.449	1.453	1.458	380
390	1.458	1.463	1.468	1.473	1.478	1.483	1.488	1.493	1.498	1.503	1.508	390
400	1.508	1.512	1.517	1.522	1.527	1.532	1.537	1.542	1.547	1.552	1.557	400
410	1.557	1.562	1.567	1.572	1.577	1.582	1.587	1.592	1.597	1.602	1.607	410
420	1.607	1.612	1.617	1.622	1.627	1.632	1.637	1.642	1.647	1.652	1.657	420
430	1.657	1.662	1.667	1.672	1.677	1.682	1.687	1.692	1.698	1.703	1.708	430
440	1.708	1.713	1.718	1.723	1.728	1.733	1.738	1.743	1.748	1.753	1.758	440
450	1.758	1.764	1.769	1.774	1.779	1.784	1.789	1.794	1.799	1.804	1.810	450
460	1.810	1.815	1.820	1.825	1.830	1.835	1.840	1.845	1.851	1.856	1.861	460
470	1.861	1.866	1.871	1.876	1.882	1.887	1.892	1.897	1.902	1.907	1.913	470
480	1.913	1.918	1.923	1.928	1.933	1.938	1.944	1.949	1.954	1.959	1.964	480
490	1.964	1.970	1.975	1.980	1.985	1.991	1.996	2.001	2.006	2.011	2.017	490
500	2.017	2.022	2.027	2.032	2.038	2.043	2.048	2.053	2.059	2.064	2.069	500
510	2.069	2.074	2.080	2.085	2.090	2.095	2.101	2.106	2.111	2.117	2.122	510
520	2.122	2.127	2.132	2.138	2.143	2.148	2.154	2.159	2.164	2.170	2.175	520
530	2.175	2.180	2.186	2.191	2.196	2.201	2.207	2.212	2.217	2.223	2.228	530
540	2.228	2.233	2.239	2.244	2.249	2.255	2.260	2.266	2.271	2.276	2.282	540
550	2.282	2.287	2.292	2.298	2.303	2.308	2.314	2.319	2.325	2.330	2.335	550
560	2.335	2.341	2.346	2.351	2.357	2.362	2.368	2.373	2.378	2.384	2.389	560
570	2.389	2.395	2.400	2.405	2.411	2.416	2.422	2.427	2.433	2.438	2.443	570
580	2.443	2.449	2.454	2.460	2.465	2.471	2.476	2.481	2.487	2.492	2.498	580
590	2.498	2.503	2.509	2.514	2.520	2.525	2.531	2.536	2.541	2.547	2.552	590
600	2.552	2.558	2.563	2.569	2.574	2.580	2.585	2.591	2.596	2.602	2.607	600
610	2.607	2.613	2.618	2.624	2.629	2.635	2.640	2.646	2.651	2.657	2.662	610
620	2.662	2.668	2.673	2.679	2.684	2.690	2.695	2.701	2.706	2.712	2.718	620
630	2.718	2.723	2.729	2.734	2.740	2.745	2.751	2.756	2.762	2.767	2.773	630
640	2.773	2.779	2.784	2.790	2.795	2.801	2.806	2.812	2.818	2.823	2.829	640
650	2.829	2.834	2.840	2.845	2.851	2.857	2.862	2.868	2.873	2.879	2.885	650
660	2.885	2.890	2.896	2.901	2.907	2.913	2.918	2.924	2.929	2.935	2.941	660
670	2.941	2.946	2.952	2.957	2.963	2.969	2.974	2.980	2.986	2.991	2.997	670
680	2.997	3.002	3.008	3.014	3.019	3.025	3.031	3.036	3.042	3.048	3.053	680
690	3.053	3.059	3.065	3.070	3.076	3.082	3.087	3.093	3.099	3.104	3.110	690
700	3.110	3.116	3.121	3.127	3.133	3.138	3.144	3.150	3.155	3.161	3.167	700
710	3.167	3.172	3.178	3.184	3.189	3.195	3.201	3.207	3.212	3.218	3.224	710
720	3.224	3.229	3.235	3.241	3.247	3.252	3.258	3.264	3.269	3.275	3.281	720
730	3.281	3.287	3.292	3.298	3.304	3.309	3.315	3.321	3.327	3.332	3.338	730
740	3.338	3.344	3.350	3.355	3.361	3.367	3.373	3.378	3.384	3.390	3.396	740
750	3.396	3.401	3.407	3.413	3.419	3.424	3.430	3.436	3.442	3.448	3.453	750
760	3.453	3.459	3.465	3.471	3.476	3.482	3.488	3.494	3.500	3.505	3.511	760
770	3.511	3.517	3.523	3.529	3.534	3.540	3.546	3.552	3.558	3.563	3.569	770
780	3.569	3.575	3.581	3.587	3.592	3.598	3.604	3.610	3.616	3.622	3.627	780
790	3.627	3.633	3.639	3.645	3.651	3.657	3.662	3.668	3.674	3.680	3.686	790

Table 8.1.12 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
800	3.686	3.692	3.697	3.703	3.709	3.715	3.721	3.727	3.733	3.738	3.744	800
810	3.744	3.750	3.756	3.762	3.768	3.774	3.779	3.785	3.791	3.797	3.803	810
820	3.803	3.809	3.815	3.821	3.826	3.832	3.838	3.844	3.850	3.856	3.862	820
830	3.862	3.868	3.874	3.879	3.885	3.891	3.897	3.903	3.909	3.915	3.921	830
840	3.921	3.927	3.933	3.938	3.944	3.950	3.956	3.962	3.968	3.974	3.980	840
850	3.980	3.986	3.992	3.998	4.004	4.009	4.015	4.021	4.027	4.033	4.039	850
860	4.039	4.045	4.051	4.057	4.063	4.069	4.075	4.081	4.087	4.093	4.099	860
870	4.099	4.105	4.110	4.116	4.122	4.128	4.134	4.140	4.146	4.152	4.158	870
880	4.158	4.164	4.170	4.176	4.182	4.188	4.194	4.200	4.206	4.212	4.218	880
890	4.218	4.224	4.230	4.236	4.242	4.248	4.254	4.260	4.266	4.272	4.278	890
900	4.278	4.284	4.290	4.296	4.302	4.308	4.314	4.320	4.326	4.332	4.338	900
910	4.338	4.344	4.350	4.356	4.362	4.368	4.374	4.380	4.386	4.392	4.398	910
920	4.398	4.404	4.410	4.416	4.422	4.428	4.434	4.440	4.446	4.452	4.458	920
930	4.458	4.465	4.471	4.477	4.483	4.489	4.495	4.501	4.507	4.513	4.519	930
940	4.519	4.525	4.531	4.537	4.543	4.549	4.555	4.561	4.567	4.574	4.580	940
950	4.580	4.586	4.592	4.598	4.604	4.610	4.616	4.622	4.628	4.634	4.640	950
960	4.640	4.647	4.653	4.659	4.665	4.671	4.677	4.683	4.689	4.695	4.701	960
970	4.701	4.707	4.714	4.720	4.726	4.732	4.738	4.744	4.750	4.756	4.762	970
980	4.762	4.769	4.775	4.781	4.787	4.793	4.799	4.805	4.811	4.818	4.824	980
990	4.824	4.830	4.836	4.842	4.848	4.854	4.860	4.867	4.873	4.879	4.885	990
1000	4.885	4.891	4.897	4.904	4.910	4.916	4.922	4.928	4.934	4.940	4.947	1000
1010	4.947	4.953	4.959	4.965	4.971	4.977	4.984	4.990	4.996	5.002	5.008	1010
1020	5.008	5.014	5.021	5.027	5.033	5.039	5.045	5.052	5.058	5.064	5.070	1020
1030	5.070	5.076	5.082	5.089	5.095	5.101	5.107	5.113	5.120	5.126	5.132	1030
1040	5.132	5.138	5.144	5.151	5.157	5.163	5.169	5.175	5.182	5.188	5.194	1040
1050	5.194	5.200	5.207	5.213	5.219	5.225	5.231	5.238	5.244	5.250	5.256	1050
1060	5.256	5.263	5.269	5.275	5.281	5.288	5.294	5.300	5.306	5.313	5.319	1060
1070	5.319	5.325	5.331	5.337	5.344	5.350	5.356	5.362	5.369	5.375	5.381	1070
1080	5.381	5.388	5.394	5.400	5.406	5.413	5.419	5.425	5.431	5.438	5.444	1080
1090	5.444	5.450	5.456	5.463	5.469	5.475	5.482	5.488	5.494	5.500	5.507	1090
1100	5.507	5.513	5.519	5.526	5.532	5.538	5.544	5.551	5.557	5.563	5.570	1100
1110	5.570	5.576	5.582	5.589	5.595	5.601	5.607	5.614	5.620	5.626	5.633	1110
1120	5.633	5.639	5.645	5.652	5.658	5.664	5.671	5.677	5.683	5.690	5.696	1120
1130	5.696	5.702	5.709	5.715	5.721	5.728	5.734	5.740	5.747	5.753	5.759	1130
1140	5.759	5.766	5.772	5.778	5.785	5.791	5.797	5.804	5.810	5.816	5.823	1140
1150	5.823	5.829	5.835	5.842	5.848	5.855	5.861	5.867	5.874	5.880	5.886	1150
1160	5.886	5.893	5.899	5.905	5.912	5.918	5.925	5.931	5.937	5.944	5.950	1160
1170	5.950	5.957	5.963	5.969	5.976	5.982	5.988	5.995	6.001	6.008	6.014	1170
1180	6.014	6.021	6.027	6.033	6.040	6.046	6.053	6.059	6.065	6.072	6.078	1180
1190	6.078	6.085	6.091	6.098	6.104	6.110	6.117	6.123	6.130	6.136	6.143	1190
1200	6.143	6.149	6.155	6.162	6.168	6.175	6.181	6.188	6.194	6.201	6.207	1200
1210	6.207	6.213	6.220	6.226	6.233	6.239	6.246	6.252	6.259	6.265	6.272	1210
1220	6.272	6.278	6.285	6.291	6.297	6.304	6.310	6.317	6.323	6.330	6.336	1220
1230	6.336	6.343	6.349	6.356	6.362	6.369	6.375	6.382	6.388	6.395	6.401	1230
1240	6.401	6.408	6.414	6.421	6.427	6.434	6.440	6.447	6.453	6.460	6.466	1240
1250	6.466	6.473	6.479	6.486	6.492	6.499	6.505	6.512	6.518	6.525	6.532	1250
1260	6.532	6.538	6.545	6.551	6.558	6.564	6.571	6.577	6.584	6.590	6.597	1260
1270	6.597	6.603	6.610	6.616	6.623	6.630	6.636	6.643	6.649	6.656	6.662	1270
1280	6.662	6.669	6.675	6.682	6.689	6.695	6.702	6.708	6.715	6.721	6.728	1280
1290	6.728	6.735	6.741	6.748	6.754	6.761	6.767	6.774	6.781	6.787	6.794	1290
1300	6.794	6.800	6.807	6.814	6.820	6.827	6.833	6.840	6.847	6.853	6.860	1300
1310	6.860	6.866	6.873	6.880	6.886	6.893	6.899	6.906	6.913	6.919	6.926	1310
1320	6.926	6.932	6.939	6.946	6.952	6.959	6.966	6.972	6.979	6.985	6.992	1320

Table 8.1.12 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1330	6.992	6.999	7.005	7.012	7.019	7.025	7.032	7.039	7.045	7.052	7.059	1330
1340	7.059	7.065	7.072	7.078	7.085	7.092	7.098	7.105	7.112	7.118	7.125	1340
1350	7.125	7.132	7.138	7.145	7.152	7.158	7.165	7.172	7.178	7.185	7.192	1350
1360	7.192	7.198	7.205	7.212	7.218	7.225	7.232	7.239	7.245	7.252	7.259	1360
1370	7.259	7.265	7.272	7.279	7.285	7.292	7.299	7.305	7.312	7.319	7.326	1370
1380	7.326	7.332	7.339	7.346	7.352	7.359	7.366	7.373	7.379	7.386	7.393	1380
1390	7.393	7.399	7.406	7.413	7.420	7.426	7.433	7.440	7.447	7.453	7.460	1390
1400	7.460	7.467	7.474	7.480	7.487	7.494	7.500	7.507	7.514	7.521	7.527	1400
1410	7.527	7.534	7.541	7.548	7.554	7.561	7.568	7.575	7.582	7.588	7.595	1410
1420	7.595	7.602	7.609	7.615	7.622	7.629	7.636	7.642	7.649	7.656	7.663	1420
1430	7.663	7.670	7.676	7.683	7.690	7.697	7.703	7.710	7.717	7.724	7.731	1430
1440	7.731	7.737	7.744	7.751	7.758	7.765	7.771	7.778	7.785	7.792	7.799	1440
1450	7.799	7.805	7.812	7.819	7.826	7.833	7.840	7.846	7.853	7.860	7.867	1450
1460	7.867	7.874	7.880	7.887	7.894	7.901	7.908	7.915	7.921	7.928	7.935	1460
1470	7.935	7.942	7.949	7.956	7.963	7.969	7.976	7.983	7.990	7.997	8.004	1470
1480	8.004	8.010	8.017	8.024	8.031	8.038	8.045	8.052	8.058	8.065	8.072	1480
1490	8.072	8.079	8.086	8.093	8.100	8.107	8.113	8.120	8.127	8.134	8.141	1490
1500	8.141	8.148	8.155	8.162	8.168	8.175	8.182	8.189	8.196	8.203	8.210	1500
1510	8.210	8.217	8.224	8.231	8.237	8.244	8.251	8.258	8.265	8.272	8.279	1510
1520	8.279	8.286	8.293	8.300	8.306	8.313	8.320	8.327	8.334	8.341	8.348	1520
1530	8.348	8.355	8.362	8.369	8.376	8.383	8.390	8.397	8.403	8.410	8.417	1530
1540	8.417	8.424	8.431	8.438	8.445	8.452	8.459	8.466	8.473	8.480	8.487	1540
1550	8.487	8.494	8.501	8.508	8.515	8.522	8.529	8.535	8.542	8.549	8.556	1550
1560	8.556	8.563	8.570	8.577	8.584	8.591	8.598	8.605	8.612	8.619	8.626	1560
1570	8.626	8.633	8.640	8.647	8.654	8.661	8.668	8.675	8.682	8.689	8.696	1570
1580	8.696	8.703	8.710	8.717	8.724	8.731	8.738	8.745	8.752	8.759	8.766	1580
1590	8.766	8.773	8.780	8.787	8.794	8.801	8.808	8.815	8.822	8.829	8.836	1590
1600	8.836	8.843	8.850	8.857	8.864	8.871	8.878	8.885	8.892	8.899	8.907	1600
1610	8.907	8.914	8.921	8.928	8.935	8.942	8.949	8.956	8.963	8.970	8.977	1610
1620	8.977	8.984	8.991	8.998	9.005	9.012	9.019	9.026	9.033	9.040	9.048	1620
1630	9.048	9.055	9.062	9.069	9.076	9.083	9.090	9.097	9.104	9.111	9.118	1630
1640	9.118	9.125	9.132	9.140	9.147	9.154	9.161	9.168	9.175	9.182	9.189	1640
1650	9.189	9.196	9.203	9.210	9.218	9.225	9.232	9.239	9.246	9.253	9.260	1650
1660	9.260	9.267	9.274	9.282	9.289	9.296	9.303	9.310	9.317	9.324	9.331	1660
1670	9.331	9.338	9.346	9.353	9.360	9.367	9.374	9.381	9.388	9.395	9.403	1670
1680	9.403	9.410	9.417	9.424	9.431	9.438	9.445	9.453	9.460	9.467	9.474	1680
1690	9.474	9.481	9.488	9.495	9.503	9.510	9.517	9.524	9.531	9.538	9.546	1690
1700	9.546	9.553	9.560	9.567	9.574	9.581	9.589	9.596	9.603	9.610	9.617	1700
1710	9.617	9.624	9.632	9.639	9.646	9.653	9.660	9.668	9.675	9.682	9.689	1710
1720	9.689	9.696	9.704	9.711	9.718	9.725	9.732	9.740	9.747	9.754	9.761	1720
1730	9.761	9.768	9.776	9.783	9.790	9.797	9.804	9.812	9.819	9.826	9.833	1730
1740	9.833	9.840	9.848	9.855	9.862	9.869	9.877	9.884	9.891	9.898	9.906	1740
1750	9.906	9.913	9.920	9.927	9.934	9.942	9.949	9.956	9.963	9.971	9.978	1750
1760	9.978	9.985	9.992	10.000	10.007	10.014	10.021	10.029	10.036	10.043	10.050	1760
1770	10.050	10.058	10.065	10.072	10.079	10.087	10.094	10.101	10.109	10.116	10.123	1770
1780	10.123	10.130	10.138	10.145	10.152	10.159	10.167	10.174	10.181	10.189	10.196	1780
1790	10.196	10.203	10.210	10.218	10.225	10.232	10.240	10.247	10.254	10.262	10.269	1790
1800	10.269	10.276	10.283	10.291	10.298	10.305	10.313	10.320	10.327	10.335	10.342	1800
1810	10.342	10.349	10.357	10.364	10.371	10.379	10.386	10.393	10.400	10.408	10.415	1810
1820	10.415	10.422	10.430	10.437	10.444	10.452	10.459	10.466	10.474	10.481	10.488	1820
1830	10.488	10.496	10.503	10.511	10.518	10.525	10.533	10.540	10.547	10.555	10.562	1830
1840	10.562	10.569	10.577	10.584	10.591	10.599	10.606	10.613	10.621	10.628	10.636	1840
1850	10.636	10.643	10.650	10.658	10.665	10.672	10.680	10.687	10.695	10.702	10.709	1850

Table 8.1.12 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1860	10.709	10.717	10.724	10.731	10.739	10.746	10.754	10.761	10.768	10.776	10.783	1860
1870	10.783	10.791	10.798	10.805	10.813	10.820	10.828	10.835	10.842	10.850	10.857	1870
1880	10.857	10.865	10.872	10.879	10.887	10.894	10.902	10.909	10.917	10.924	10.931	1880
1890	10.931	10.939	10.946	10.954	10.961	10.968	10.976	10.983	10.991	10.998	11.006	1890
1900	11.006	11.013	11.021	11.028	11.035	11.043	11.050	11.058	11.065	11.073	11.080	1900
1910	11.080	11.088	11.095	11.102	11.110	11.117	11.125	11.132	11.140	11.147	11.155	1910
1920	11.155	11.162	11.170	11.177	11.184	11.192	11.199	11.207	11.214	11.222	11.229	1920
1930	11.229	11.237	11.244	11.252	11.259	11.267	11.274	11.282	11.289	11.297	11.304	1930
1940	11.304	11.312	11.319	11.327	11.334	11.342	11.349	11.357	11.364	11.372	11.379	1940
1950	11.379	11.387	11.394	11.402	11.409	11.417	11.424	11.432	11.439	11.447	11.454	1950
1960	11.454	11.462	11.469	11.477	11.484	11.492	11.499	11.507	11.514	11.522	11.529	1960
1970	11.529	11.537	11.544	11.552	11.559	11.567	11.574	11.582	11.590	11.597	11.605	1970
1980	11.605	11.612	11.620	11.627	11.635	11.642	11.650	11.657	11.665	11.672	11.680	1980
1990	11.680	11.688	11.695	11.703	11.710	11.718	11.725	11.733	11.740	11.748	11.756	1990
2000	11.756	11.763	11.771	11.778	11.786	11.793	11.801	11.808	11.816	11.824	11.831	2000
2010	11.831	11.839	11.846	11.854	11.861	11.869	11.877	11.884	11.892	11.899	11.907	2010
2020	11.907	11.914	11.922	11.930	11.37	11.945	11.952	11.960	11.968	11.975	11.983	2020
2030	11.983	11.990	11.998	12.005	12.013	12.021	12.028	12.036	12.043	12.051	12.059	2030
2040	12.059	12.066	12.074	12.081	12.089	12.097	12.104	12.112	12.119	12.127	12.135	2040
2050	12.135	12.142	12.150	12.157	12.165	12.173	12.180	12.188	12.196	12.203	12.211	2050
2060	12.211	12.218	12.226	12.234	12.241	12.249	12.257	12.264	12.272	12.279	12.287	2060
2070	12.287	12.295	12.302	12.310	12.318	12.325	12.333	12.340	12.348	12.356	12.363	2070
2080	12.363	12.371	12.379	12.386	12.394	12.402	12.409	12.417	12.424	12.432	12.440	2080
2090	12.440	12.447	12.455	12.463	12.470	12.478	12.486	12.193	12.501	12.509	12.516	2090
2100	12.516	12.524	12.532	12.539	12.547	12.555	12.562	12.570	12.577	12.585	12.593	2100
2110	12.593	12.600	12.608	12.616	12.623	12.631	12.639	12.646	12.654	12.662	12.669	2110
2120	12.669	12.677	12.685	12.693	12.700	12.708	12.716	12.723	12.731	12.739	12.746	2120
2130	12.746	12.754	12.762	12.769	12.777	12.785	12.792	12.800	12.808	12.815	12.823	2130
2140	12.823	12.831	12.838	12.846	12.854	12.862	12.869	12.877	12.885	12.892	12.900	2140
2150	12.900	12.908	12.915	12.923	12.931	12.938	12.946	12.954	12.962	12.969	12.977	2150
2160	12.977	12.985	12.992	13.000	13.008	13.016	13.023	13.031	13.039	13.046	13.054	2160
2170	13.054	13.062	13.069	13.077	13.085	13.093	13.100	13.108	13.116	13.123	13.131	2170
2180	13.131	13.139	13.147	13.154	13.162	13.170	13.178	13.185	13.193	13.201	13.208	2180
2190	13.208	13.216	13.224	13.232	13.239	13.247	13.255	13.263	13.270	13.278	13.286	2190
2200	13.286	13.293	13.301	13.309	13.317	13.324	13.332	13.340	13.348	13.355	13.363	2200
2210	13.363	13.371	13.379	13.386	13.394	13.402	13.409	13.417	13.425	13.433	13.440	2210
2220	13.440	13.448	13.456	13.464	13.471	13.479	13.487	13.495	13.502	13.510	13.518	2220
2230	13.518	13.526	13.533	13.541	13.549	13.557	13.564	13.572	13.580	13.588	13.595	2230
2240	13.595	13.603	13.611	13.619	13.627	13.634	13.642	13.650	13.658	13.665	13.673	2240
2250	13.673	13.681	13.689	13.696	13.704	13.712	13.720	13.727	13.735	13.743	13.751	2250
2260	13.751	13.759	13.766	13.774	13.782	13.790	13.797	13.805	13.813	13.821	13.828	2260
2270	13.828	13.836	13.844	13.852	13.860	13.867	13.875	13.883	13.891	13.898	13.906	2270
2280	13.906	13.914	13.922	13.930	13.937	13.945	13.953	13.961	13.968	13.976	13.984	2280
2290	13.984	13.992	14.000	14.007	14.015	14.023	14.031	14.039	14.046	14.054	14.062	2290
2300	14.062	14.070	14.078	14.085	14.093	14.101	14.109	14.116	14.124	14.132	14.140	2300
2310	14.140	14.148	14.155	14.163	14.171	14.179	14.187	14.194	14.202	14.210	14.218	2310
2320	14.218	14.226	14.233	14.241	14.249	14.257	14.265	14.272	14.280	14.288	14.296	2320
2330	14.296	14.304	14.311	14.319	14.327	14.335	14.343	14.350	14.358	14.366	14.374	2330
2340	14.374	14.382	14.389	14.397	14.405	14.413	14.421	14.429	14.436	14.444	14.452	2340
2350	14.452	14.460	14.468	14.475	14.483	14.491	14.499	14.507	14.514	14.522	14.530	2350
2360	14.530	14.538	14.546	14.554	14.561	14.569	14.577	14.585	14.593	14.600	14.608	2360
2370	14.608	14.616	14.624	14.632	14.640	14.647	14.655	14.663	14.671	14.679	14.686	2370
2380	14.686	14.694	14.702	14.710	14.718	14.726	14.733	14.741	14.749	14.757	14.765	2380

Table 8.1.12 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2390	14.765	14.772	14.780	14.788	14.796	14.804	14.812	14.819	14.827	14.835	14.843	2390
2400	14.843	14.851	14.859	14.866	14.874	14.882	14.890	14.898	14.906	14.913	14.921	2400
2410	14.921	14.929	14.937	14.945	14.953	14.960	14.968	14.976	14.984	14.992	15.000	2410
2420	15.000	15.007	15.015	15.023	15.031	15.039	15.047	15.054	15.062	15.070	15.078	2420
2430	15.078	15.086	15.094	15.101	15.109	15.117	15.125	15.133	15.141	15.148	15.156	2430
2440	15.156	15.164	15.172	15.180	15.188	15.195	15.203	15.211	15.219	15.227	15.235	2440
2450	15.235	15.242	15.250	15.258	15.266	15.274	15.282	15.289	15.297	15.305	15.313	2450
2460	15.313	15.321	15.329	15.337	15.344	15.352	15.360	15.368	15.376	15.384	15.391	2460
2470	15.391	15.399	15.407	15.415	15.423	15.431	15.438	15.446	15.454	15.462	15.470	2470
2480	15.470	15.478	15.486	15.493	15.501	15.509	15.517	15.525	15.533	15.540	15.548	2480
2490	15.548	15.556	15.564	15.572	15.580	15.587	15.595	15.603	15.611	15.619	15.627	2490
2500	15.627	15.635	15.642	15.650	15.658	15.666	15.674	15.682	15.689	15.697	15.705	2500
2510	15.705	15.713	15.721	15.729	15.737	15.744	15.752	15.760	15.768	15.776	15.784	2510
2520	15.784	15.791	15.799	15.807	15.815	15.823	15.831	15.839	15.846	15.854	15.862	2520
2530	15.862	15.870	15.878	15.886	15.893	15.901	15.909	15.917	15.925	15.933	15.941	2530
2540	15.941	15.948	15.956	15.964	15.972	15.980	15.988	15.995	16.003	16.011	16.019	2540
2550	16.019	16.027	16.035	16.043	16.050	16.058	16.066	16.074	16.082	16.090	16.097	2550
2560	16.097	16.105	16.113	16.121	16.129	16.137	16.145	16.152	16.160	16.168	16.176	2560
2570	16.176	16.184	16.192	16.199	16.207	16.215	16.223	16.231	16.239	16.247	16.254	2570
2580	16.254	16.262	16.270	16.278	16.286	16.294	16.301	16.309	16.317	16.325	16.333	2580
2590	16.333	16.341	16.349	16.356	16.364	16.372	16.380	16.388	16.396	16.403	16.411	2590
2600	16.411	16.419	16.427	16.435	16.443	16.450	16.458	16.466	16.474	16.482	16.490	2600
2610	16.490	16.498	16.505	16.513	16.521	16.529	16.537	16.545	16.552	16.560	16.568	2610
2620	16.568	16.576	16.584	16.592	16.599	16.607	16.615	16.623	16.631	16.639	16.646	2620
2630	16.646	16.654	16.662	16.670	16.678	16.686	16.694	16.701	16.709	16.717	16.725	2630
2640	16.725	16.733	16.741	16.748	16.756	16.764	16.772	16.780	16.788	16.795	16.803	2640
2650	16.803	16.811	16.819	16.827	16.835	16.842	16.850	16.858	16.866	16.874	16.882	2650
2660	16.882	16.889	16.897	16.905	16.913	16.921	16.929	16.936	16.944	16.952	16.960	2660
2670	16.960	16.968	16.976	16.983	16.991	16.999	17.007	17.015	17.022	17.030	17.038	2670
2680	17.038	17.046	17.054	17.062	17.069	17.077	17.085	17.093	17.101	17.109	17.116	2680
2690	17.116	17.124	17.132	17.140	17.148	17.156	17.163	17.171	17.179	17.187	17.195	2690
2700	17.195	17.202	17.210	17.218	17.226	17.234	17.242	17.249	17.257	17.265	17.273	2700
2710	17.273	17.281	17.288	17.296	17.304	17.312	17.320	17.328	17.335	17.343	17.351	2710
2720	17.351	17.359	17.367	17.374	17.382	17.390	17.398	17.406	17.413	17.421	17.429	2720
2730	17.429	17.437	17.445	17.453	17.460	17.468	17.476	17.484	17.492	17.499	17.507	2730
2740	17.507	17.515	17.523	17.531	17.538	17.546	17.554	17.562	17.570	17.577	17.585	2740
2750	17.585	17.593	17.601	17.609	17.616	17.624	17.632	17.640	17.648	17.655	17.663	2750
2760	17.663	17.671	17.679	17.687	17.694	17.702	17.710	17.718	17.726	17.733	17.741	2760
2770	17.741	17.749	17.757	17.765	17.772	17.780	17.788	17.796	17.804	17.811	17.819	2770
2780	17.819	17.827	17.835	17.842	17.850	17.858	17.866	17.874	17.881	17.889	17.897	2780
2790	17.897	17.905	17.913	17.920	17.928	17.936	17.944	17.951	17.959	17.967	17.975	2790
2800	17.975	17.983	17.990	17.998	18.006	18.014	18.021	18.029	18.037	18.045	18.053	2800
2810	18.053	18.060	18.068	18.076	18.084	18.091	18.099	18.107	18.115	18.123	18.130	2810
2820	18.130	18.138	18.146	18.154	18.161	18.169	18.177	18.185	18.192	18.200	18.208	2820
2830	18.208	18.216	18.223	18.231	18.239	18.247	18.255	18.262	18.270	18.278	18.286	2830
2840	18.286	18.293	18.301	18.309	18.317	18.324	18.332	18.340	18.348	18.355	18.363	2840
2850	18.363	18.371	18.379	18.386	18.394	18.402	18.410	18.417	18.425	18.433	18.441	2850
2860	18.441	18.448	18.456	18.464	18.472	18.479	18.487	18.495	18.502	18.510	18.518	2860
2870	18.518	18.526	18.533	18.541	18.549	18.557	18.564	18.572	18.580	18.588	18.595	2870
2880	18.595	18.603	18.611	18.619	18.626	18.634	18.642	18.649	18.657	18.665	18.673	2880
2890	18.673	18.680	18.688	18.696	18.703	18.711	18.719	18.727	18.734	18.742	18.750	2890
2900	18.750	18.758	18.765	18.773	18.781	18.788	18.796	18.804	18.812	18.819	18.827	2900
2910	18.827	18.835	18.842	18.850	18.858	18.865	18.873	18.881	18.889	18.896	18.904	2910

Table 8.1.12 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2920	18.904	18.912	18.919	18.927	18.935	18.943	18.950	18.958	18.966	18.973	18.981	2920
2930	18.981	18.989	18.996	19.004	19.012	19.019	19.027	19.035	19.043	19.050	19.058	2930
2940	19.058	19.066	19.073	19.081	19.089	19.096	19.104	19.112	19.119	19.127	19.135	2940
2950	19.135	19.143	19.150	19.158	19.165	19.173	19.181	19.188	19.196	19.204	19.211	2950
2960	19.211	19.219	19.227	19.234	19.242	19.250	19.257	19.265	19.273	19.280	19.288	2960
2970	19.288	19.296	19.303	19.311	19.319	19.326	19.334	19.342	19.349	19.357	19.365	2970
2980	19.365	19.372	19.380	19.388	19.395	19.403	19.411	19.418	19.426	19.434	19.441	2980
2990	19.441	19.449	19.457	19.464	19.472	19.479	19.487	19.495	19.502	19.510	19.518	2990
3000	19.518	19.525	19.533	19.541	19.548	19.556	19.563	19.571	19.579	19.586	19.594	3000
3010	19.594	19.602	19.609	19.617	19.624	19.632	19.640	19.647	19.655	19.663	19.670	3010
3020	19.670	19.678	19.685	19.693	19.701	19.708	19.716	19.723	19.731	19.739	19.746	3020
3030	19.746	19.754	19.761	19.769	19.777	19.784	19.792	19.800	19.807	19.815	19.822	3030
3040	19.822	19.830	19.837	19.845	19.853	19.860	19.868	19.875	19.883	19.891	19.898	3040
3050	19.898	19.906	19.913	19.921	19.929	19.936	19.944	19.951	19.959	19.966	19.974	3050
3060	19.974	19.982	19.989	19.997	20.004	20.012	20.019	20.027	20.034	20.042	20.050	3060
3070	20.050	20.057	20.065	20.072	20.080	20.087	20.095	20.102	20.110	20.117	20.125	3070
3080	20.125	20.132	20.140	20.148	20.155	20.163	20.170	20.178	20.185	20.193	20.200	3080
3090	20.200	20.208	20.215	20.223	20.230	20.238	20.245	20.253	20.260	20.268	20.275	3090
3100	20.275	20.283	20.290	20.297	20.305	20.312	20.320	20.327	20.335	20.342	20.350	3100
3110	20.350	20.357	20.365	20.372	20.380	20.387	20.394	20.402	20.409	20.417	20.424	3110
3120	20.424	20.432	20.439	20.446	20.454	20.461	20.469	20.476	20.483	20.491	20.498	3120
3130	20.498	20.506	20.513	20.520	20.528	20.535	20.543	20.550	20.557	20.565	20.572	3130
3140	20.572	20.579	20.587	20.594	20.601	20.609	20.616	20.623	20.631	20.638	20.645	3140
3150	20.645	20.653	20.660	20.667	20.675	20.682	20.689	20.697	20.704	20.711	20.718	3150
3160	20.718	20.726	20.733	20.740	20.748	20.755	20.762	20.769	20.777	20.784	20.791	3160
3170	20.791	20.798	20.806	20.813	20.820	20.827	20.834	20.842	20.849	20.856	20.863	3170
3180	20.863	20.870	20.878	20.885	20.892	20.899	20.906	20.914	20.921	20.928	20.935	3180
3190	20.935	20.942	20.949	20.956	20.964	20.971	20.978	20.985	20.992	20.999	21.006	3190
3200	21.006	21.013	21.021	21.028	21.035	21.042	21.049	21.056	21.063	21.070	21.077	3200
3210	21.077	21.084	21.091	21.098	21.105							3210

T/C Type S - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.13 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-50	-0.236	-0.232	-0.228	-0.224	-0.220	-0.215	-0.211	-0.207	-0.203	-0.199	-0.194	-50
-40	-0.194	-0.190	-0.186	-0.181	-0.177	-0.173	-0.168	-0.164	-0.159	-0.155	-0.150	-40
-30	-0.150	-0.145	-0.141	-0.136	-0.132	-0.127	-0.122	-0.117	-0.112	-0.108	-0.103	-30
-20	-0.103	-0.098	-0.093	-0.088	-0.083	-0.078	-0.073	-0.068	-0.063	-0.058	-0.053	-20
-10	-0.053	-0.048	-0.042	-0.037	-0.032	-0.027	-0.021	-0.016	-0.011	-0.005	-0.000	-10
0	0.000	0.005	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.050	0.055	0
10	0.055	0.061	0.067	0.072	0.078	0.084	0.090	0.095	0.101	0.107	0.113	10
20	0.113	0.119	0.125	0.131	0.137	0.142	0.148	0.154	0.161	0.167	0.173	20
30	0.173	0.179	0.185	0.191	0.197	0.203	0.210	0.216	0.222	0.228	0.235	30
40	0.235	0.241	0.247	0.254	0.260	0.266	0.273	0.279	0.286	0.292	0.299	40
50	0.299	0.305	0.312	0.318	0.325	0.331	0.338	0.345	0.351	0.358	0.365	50
60	0.365	0.371	0.378	0.385	0.391	0.398	0.405	0.412	0.419	0.425	0.432	60
70	0.432	0.439	0.446	0.453	0.460	0.467	0.474	0.481	0.488	0.495	0.502	70
80	0.502	0.509	0.516	0.523	0.530	0.537	0.544	0.551	0.558	0.566	0.573	80

Table 8.1.13 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
90	0.573	0.580	0.587	0.594	0.602	0.609	0.616	0.623	0.631	0.638	0.645	90
100	0.645	0.653	0.660	0.667	0.675	0.682	0.690	0.697	0.704	0.712	0.719	100
110	0.719	0.727	0.734	0.742	0.749	0.754	0.764	0.772	0.780	0.787	0.795	110
120	0.795	0.802	0.810	0.818	0.825	0.833	0.841	0.848	0.856	0.864	0.872	120
130	0.872	0.879	0.887	0.895	0.903	0.910	0.918	0.926	0.934	0.942	0.950	130
140	0.950	0.957	0.965	0.973	0.981	0.989	0.997	1.005	1.013	1.021	1.029	140
150	1.029	1.037	1.045	1.053	1.061	1.069	1.077	1.085	1.093	1.101	1.109	150
160	1.109	1.117	1.125	1.133	1.141	1.149	1.158	1.166	1.174	1.182	1.190	160
170	1.190	1.198	1.207	1.215	1.223	1.231	1.240	1.248	1.256	1.264	1.273	170
180	1.273	1.281	1.289	1.297	1.306	1.314	1.322	1.331	1.339	1.347	1.356	180
190	1.356	1.364	1.373	1.381	1.389	1.398	1.406	1.415	1.423	1.432	1.440	190
200	1.440	1.448	1.457	1.465	1.474	1.482	1.491	1.499	1.508	1.516	1.525	200
210	1.525	1.534	1.542	1.551	1.559	1.568	1.576	1.595	1.594	1.602	1.611	210
220	1.611	1.620	1.628	1.637	1.645	1.654	1.663	1.671	1.680	1.689	1.698	220
230	1.698	1.706	1.715	1.724	1.732	1.741	1.750	1.759	1.767	1.776	1.785	230
240	1.785	1.794	1.802	1.811	1.820	1.829	1.838	1.846	1.855	1.864	1.873	240
250	1.873	1.882	1.891	1.899	1.908	1.917	1.926	1.935	1.944	1.953	1.962	250
260	1.962	1.971	1.979	1.988	1.997	2.006	2.015	2.024	2.033	2.042	2.051	260
270	2.051	2.060	2.069	2.078	2.087	2.096	2.105	2.114	2.123	2.132	2.141	270
280	2.141	2.150	2.159	2.168	2.177	2.186	2.195	2.204	2.213	2.222	2.232	280
290	2.232	2.241	2.250	2.259	2.268	2.277	2.286	2.295	2.304	2.314	2.323	290
300	2.323	2.332	2.341	2.350	2.359	2.368	2.378	2.387	2.396	2.405	2.414	300
310	2.414	2.424	2.433	2.442	2.451	2.460	2.470	2.479	2.488	2.497	2.506	310
320	2.506	2.516	2.525	2.534	2.543	2.553	2.562	2.571	2.581	2.590	2.599	320
330	2.599	2.608	2.618	2.627	2.636	2.646	2.655	2.664	2.674	2.683	2.692	330
340	2.692	2.702	2.711	2.720	2.730	2.739	2.748	2.758	2.767	2.776	2.786	340
350	2.786	2.795	2.805	2.814	2.823	2.833	2.842	2.852	2.861	2.870	2.880	350
360	2.880	2.889	2.899	2.908	2.917	2.927	2.936	2.946	2.955	2.965	2.974	360
370	2.974	2.984	2.993	3.003	3.012	3.022	3.031	3.041	3.050	3.059	3.069	370
380	3.069	3.078	3.088	3.097	3.107	3.117	3.126	3.136	3.145	3.155	3.164	380
390	3.164	3.174	3.183	3.193	3.202	3.212	3.221	3.231	3.241	3.250	3.260	390
400	3.260	3.269	3.279	3.288	3.298	3.308	3.317	3.327	3.336	3.346	3.356	400
410	3.356	3.365	3.375	3.384	3.394	3.404	3.413	3.423	3.433	3.442	3.452	410
420	3.452	3.462	3.471	3.481	3.491	3.500	3.510	3.520	3.529	3.539	3.549	420
430	3.549	3.558	3.568	3.578	3.587	3.597	3.607	3.616	3.626	3.636	3.645	430
440	3.645	3.655	3.665	3.675	3.684	3.694	3.704	3.714	3.723	3.733	3.743	440
450	3.743	3.752	3.762	3.772	3.782	3.791	3.801	3.811	3.821	3.831	3.840	450
460	3.840	3.850	3.860	3.870	3.879	3.889	3.899	3.909	3.919	3.928	3.938	460
470	3.938	3.948	3.958	3.968	3.977	3.987	3.997	4.007	4.017	4.027	4.036	470
480	4.036	4.046	4.056	4.066	4.076	4.086	4.095	4.105	4.115	4.125	4.135	480
490	4.135	4.145	4.155	4.164	4.174	4.184	4.194	4.204	4.214	4.224	4.234	490
500	4.234	4.243	4.253	4.263	4.273	4.283	4.293	4.303	4.313	4.323	4.333	500
510	4.333	4.343	4.352	4.362	4.372	4.382	4.392	4.402	4.412	4.422	4.432	510
520	4.432	4.442	4.452	4.462	4.472	4.482	4.492	4.502	4.512	4.522	4.532	520
530	4.532	4.542	4.552	4.562	4.572	4.582	4.592	4.602	4.612	4.622	4.632	530
540	4.632	4.642	4.652	4.662	4.672	4.682	4.692	4.702	4.712	4.722	4.732	540
550	4.732	4.742	4.752	4.762	4.772	4.782	4.792	4.802	4.812	4.822	4.832	550
560	4.832	4.842	4.852	4.862	4.873	4.883	4.893	4.903	4.913	4.923	4.933	560
570	4.933	4.943	4.953	4.963	4.973	4.984	4.994	5.004	5.014	5.024	5.034	570
580	5.034	5.044	5.054	5.065	5.075	5.085	5.095	5.105	5.115	5.125	5.136	580
590	5.136	5.146	5.156	5.166	5.176	5.186	5.197	5.207	5.217	5.227	5.237	590
600	5.237	5.247	5.258	5.268	5.278	5.288	5.298	5.309	5.319	5.329	5.339	600
610	5.339	5.350	5.360	5.370	5.380	5.391	5.401	5.411	5.421	5.431	5.442	610

Table 8.1.13 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
620	5.442	5.452	5.462	5.473	5.483	5.493	5.503	5.514	5.524	5.534	5.544	620
630	5.544	5.555	5.565	5.575	5.586	5.596	5.606	5.617	5.627	5.637	5.648	630
640	5.648	5.658	5.668	5.679	5.689	5.700	5.710	5.720	5.731	5.741	5.751	640
650	5.751	5.762	5.772	5.782	5.793	5.803	5.814	5.824	5.834	5.845	5.855	650
660	5.855	5.866	5.876	5.887	5.897	5.907	5.918	5.928	5.939	5.949	5.960	660
670	5.960	5.970	5.980	5.991	6.001	6.012	6.022	6.033	6.043	6.054	6.064	670
680	6.064	6.075	6.085	6.096	6.106	6.117	6.127	6.138	6.148	6.159	6.169	680
690	6.169	6.180	6.190	6.201	6.211	6.222	6.232	6.243	6.253	6.264	6.274	690
700	6.274	6.285	6.265	6.306	6.316	6.327	6.338	6.348	6.359	6.369	6.380	700
710	6.380	6.390	6.401	6.412	6.422	6.433	6.443	6.454	6.465	6.475	6.486	710
720	6.486	6.496	6.507	6.518	6.528	6.539	6.549	6.560	6.571	6.581	6.592	720
730	6.592	6.603	6.613	6.624	6.635	6.645	6.656	6.667	6.677	6.688	6.699	730
740	6.699	6.709	6.720	6.731	6.741	6.752	6.763	6.773	6.784	6.795	6.805	740
750	6.805	6.816	6.827	6.838	6.848	6.859	6.870	6.880	6.891	6.902	6.913	750
760	6.913	6.923	6.934	6.945	6.956	6.966	6.977	6.988	6.999	7.009	7.020	760
770	7.020	7.031	7.042	7.053	7.063	7.074	7.085	7.096	7.107	7.117	7.128	770
780	7.128	7.139	7.150	7.161	7.171	7.182	7.193	7.204	7.215	7.225	7.236	780
790	7.236	7.247	7.258	7.269	7.280	7.291	7.301	7.312	7.323	7.334	7.345	790
800	7.345	7.356	7.367	7.377	7.388	7.399	7.410	7.421	7.432	7.443	7.454	800
810	7.454	7.465	7.476	7.486	7.497	7.508	7.519	7.530	7.541	7.552	7.563	810
820	7.563	7.574	7.585	7.596	7.607	7.618	7.629	7.640	7.651	7.661	7.672	820
830	7.672	7.683	7.694	7.705	7.716	7.727	7.738	7.749	7.760	7.771	7.782	830
840	7.782	7.793	7.804	7.815	7.826	7.837	7.848	7.859	7.870	7.881	7.892	840
850	7.892	7.904	7.915	7.926	7.937	7.948	7.959	7.970	7.981	7.992	8.003	850
860	8.003	8.014	8.025	8.036	8.047	8.058	8.069	8.081	8.092	8.103	8.114	860
870	8.114	8.125	8.136	8.147	8.158	8.169	8.180	8.192	8.203	8.214	8.225	870
880	8.225	8.236	8.247	8.258	8.270	8.281	8.292	8.303	8.314	8.325	8.336	880
890	8.336	8.348	8.359	8.370	8.381	8.392	8.404	8.415	8.426	8.437	8.448	890
900	8.448	8.460	8.471	8.482	8.493	8.504	8.516	8.527	8.538	8.549	8.560	900
910	8.560	8.572	8.583	8.594	8.605	8.617	8.628	8.639	8.650	8.662	8.673	910
920	8.673	8.684	8.695	8.707	8.718	8.729	8.741	8.752	8.763	8.774	8.786	920
930	8.786	8.797	8.808	8.820	8.831	8.842	8.854	8.865	8.876	8.888	8.899	930
940	8.899	8.910	8.922	8.933	8.944	8.956	8.967	8.978	8.990	9.001	9.012	940
950	9.012	9.024	9.035	9.047	9.058	9.069	9.081	9.092	9.103	9.115	9.126	950
960	9.126	9.138	9.149	9.160	9.172	9.183	9.195	9.206	9.217	9.229	9.240	960
970	9.240	9.252	9.263	9.275	9.286	9.298	9.309	9.320	9.332	9.343	9.355	970
980	9.355	9.366	9.378	9.389	9.401	9.412	9.424	9.435	9.447	9.458	9.470	980
990	9.470	9.481	9.493	9.504	9.516	9.527	9.539	9.550	9.562	9.573	9.585	990
1000	9.585	9.596	9.608	9.619	9.631	9.642	9.654	9.665	9.677	9.689	9.700	1000
1010	9.700	9.712	9.723	9.735	9.746	9.758	9.770	9.781	9.793	9.804	9.816	1010
1020	9.816	9.828	9.839	9.851	9.862	9.874	9.886	9.897	9.909	9.920	9.932	1020
1030	9.932	9.944	9.955	9.967	9.979	9.990	10.002	10.013	10.025	10.037	10.048	1030
1040	10.048	10.060	10.072	10.083	10.095	10.107	10.118	10.130	10.142	10.154	10.165	1040
1050	10.165	10.177	10.189	10.200	10.212	10.224	10.235	10.247	10.259	10.271	10.282	1050
1060	10.282	10.294	10.306	10.318	10.329	10.341	10.353	10.364	10.376	10.388	10.400	1060
1070	10.400	10.411	10.423	10.435	10.447	10.459	10.470	10.482	10.494	10.506	10.517	1070
1080	10.517	10.529	10.541	10.553	10.565	10.576	10.588	10.600	10.612	10.624	10.635	1080
1090	10.635	10.647	10.659	10.671	10.683	10.694	10.706	10.718	10.730	10.742	10.754	1090
1100	10.754	10.765	10.777	10.789	10.801	10.813	10.825	10.836	10.848	10.860	10.872	1100
1120	10.991	11.003	11.014	11.026	11.038	11.050	11.062	11.074	11.086	11.098	11.110	1120
1130	11.110	11.121	11.133	11.145	11.157	11.169	11.181	11.193	11.205	11.217	11.229	1130
1140	11.229	11.241	11.252	11.264	11.276	11.288	11.300	11.312	11.324	11.336	11.348	1140
1150	11.348	11.360	11.372	11.384	11.408	11.420	11.432	11.443	11.455	11.467	11.467	1150

Table 8.1.13 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1160	11.467	11.479	11.491	11.503	11.515	11.527	11.539	11.551	11.563	11.575	11.587	1160
1170	11.587	11.599	11.611	11.623	11.635	11.647	11.659	11.671	11.683	11.695	11.707	1170
1180	11.707	11.719	11.731	11.743	11.755	11.767	11.779	11.791	11.803	11.815	11.827	1180
1190	11.827	11.839	11.851	11.863	11.875	11.887	11.899	11.911	11.923	11.935	11.947	1190
1200	11.947	11.959	11.971	11.983	11.995	12.007	12.019	12.031	12.043	12.055	12.067	1200
1210	12.067	12.079	12.091	12.103	12.116	12.128	12.140	12.152	12.164	12.176	12.188	1210
1220	12.188	12.200	12.212	12.224	12.236	12.248	12.260	12.272	12.284	12.296	12.308	1220
1230	12.308	12.320	12.332	12.345	12.357	12.369	12.381	12.393	12.405	12.417	12.429	1230
1240	12.429	12.441	12.453	12.465	12.477	12.489	12.501	12.514	12.526	12.538	12.550	1240
1250	12.550	12.562	12.574	12.586	12.598	12.610	12.622	12.634	12.647	12.659	12.671	1250
1260	12.671	12.683	12.695	12.707	12.719	12.731	12.743	12.755	12.767	12.780	12.792	1260
1270	12.792	12.804	12.816	12.828	12.840	12.852	12.864	12.876	12.888	12.901	12.913	1270
1280	12.913	12.925	12.937	12.949	12.961	12.973	12.985	12.997	13.010	13.022	13.034	1280
1290	13.034	13.046	13.058	13.070	13.082	13.094	13.107	13.119	13.131	13.143	13.155	1290
1300	13.155	13.167	13.179	13.191	13.203	13.216	13.228	13.240	13.252	13.264	13.276	1300
1310	13.276	13.288	13.300	13.313	13.325	13.337	13.349	13.361	13.373	13.385	13.397	1310
1320	13.397	13.410	13.422	13.434	13.446	13.458	13.470	13.482	13.495	13.507	13.519	1320
1330	13.519	13.531	13.543	13.555	13.567	13.579	13.592	13.604	13.616	13.628	13.640	1330
1340	13.640	13.652	13.664	13.677	13.689	13.701	13.713	13.725	13.737	13.749	13.761	1340
1350	13.761	13.774	13.786	13.798	13.810	13.822	13.834	13.846	13.859	13.871	13.883	1350
1360	13.883	13.895	13.907	13.919	13.931	13.943	13.956	13.968	13.980	13.992	14.004	1360
1370	14.004	14.016	14.028	14.040	14.053	14.065	14.077	14.089	14.101	14.113	14.125	1370
1380	14.125	14.138	14.150	14.162	14.174	14.186	14.198	14.210	14.222	14.235	14.247	1380
1390	14.247	14.259	14.271	14.283	14.295	14.307	14.319	14.332	14.344	14.356	14.368	1390
1400	14.368	14.380	14.392	14.404	14.416	14.429	14.441	14.453	14.465	14.477	14.489	1400
1410	14.489	14.501	14.513	14.526	14.538	14.550	14.562	14.574	14.586	14.598	14.610	1410
1420	14.610	14.622	14.635	14.647	14.659	14.671	14.683	14.695	14.707	14.719	14.731	1420
1430	14.731	14.744	14.756	14.768	14.780	14.792	14.804	14.816	14.828	14.840	14.852	1430
1440	14.852	14.865	14.877	14.889	14.901	14.913	14.925	14.937	14.949	14.961	14.973	1440
1450	14.973	14.985	14.998	15.010	15.022	15.034	15.046	15.058	15.070	15.082	15.094	1450
1460	15.094	15.106	15.118	15.130	15.143	15.155	15.167	15.179	15.191	15.203	15.215	1460
1470	15.215	15.227	15.239	15.251	15.263	15.275	15.287	15.299	15.311	15.324	15.336	1470
1480	15.336	15.348	15.360	15.372	15.384	15.396	15.408	15.420	15.432	15.444	15.456	1480
1490	15.456	15.468	15.480	15.492	15.504	15.516	15.528	15.540	15.552	15.564	15.576	1490
1500	15.576	15.589	15.601	15.613	15.625	15.637	15.649	15.661	15.673	15.685	15.697	1500
1510	15.697	15.709	15.721	15.733	15.745	15.757	15.769	15.781	15.793	15.805	15.817	1510
1520	15.817	15.829	15.841	15.853	15.865	15.877	15.889	15.901	15.913	15.925	15.937	1520
1530	15.937	15.949	15.961	15.973	15.985	15.997	16.009	16.021	16.033	16.045	16.057	1530
1540	16.057	16.069	16.080	16.092	16.104	16.116	16.128	16.140	16.152	16.164	16.176	1540
1550	16.176	16.188	16.200	16.212	16.224	16.236	16.248	16.260	16.272	16.284	16.296	1550
1560	16.296	16.308	16.319	16.331	16.343	16.355	16.367	16.379	16.391	16.403	16.415	1560
1570	16.415	16.427	16.439	16.451	16.462	16.474	16.486	16.498	16.510	16.522	16.534	1570
1580	16.534	16.546	16.558	16.569	16.581	16.593	16.605	16.617	16.629	16.641	16.653	1580
1590	16.653	16.664	16.676	16.688	16.700	16.712	16.724	16.736	16.747	16.759	16.771	1590
1600	16.771	16.783	16.795	16.807	16.819	16.830	16.842	16.854	16.866	16.878	16.890	1600
1610	16.890	16.901	16.913	16.925	16.937	16.949	16.960	16.972	16.984	16.996	17.008	1610
1620	17.008	17.019	17.031	17.043	17.055	17.067	17.078	17.090	17.102	17.114	17.125	1620
1630	17.125	17.137	17.149	17.161	17.173	17.184	17.196	17.208	17.220	17.231	17.243	1630
1640	17.243	17.255	17.267	17.278	17.290	17.302	17.313	17.325	17.337	17.349	17.360	1640
1650	17.360	17.372	17.384	17.396	17.407	17.419	17.431	17.442	17.454	17.466	17.477	1650
1660	17.477	17.489	17.501	17.512	17.524	17.536	17.548	17.559	17.571	17.583	17.594	1660
1670	17.594	17.606	17.617	17.629	17.641	17.652	17.664	17.676	17.687	17.699	17.711	1670
1680	17.711	17.722	17.734	17.745	17.757	17.769	17.780	17.792	17.803	17.815	17.826	1680

Table 8.1.13 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1690	17.826	17.838	17.850	17.861	17.873	17.884	17.896	17.907	17.919	17.930	17.942	1690
1700	17.942	17.953	17.965	17.976	17.988	17.999	18.010	18.022	18.033	18.045	18.056	1700
1710	18.056	18.068	18.079	18.090	18.102	18.113	18.124	18.136	18.147	18.158	18.170	1710
1720	18.170	18.181	18.192	18.204	18.215	18.226	18.237	18.249	18.260	18.271	18.282	1720
1730	18.282	18.293	18.305	18.316	18.327	18.338	18.349	18.360	18.372	18.383	18.394	1730
1740	18.394	18.405	18.416	18.427	18.438	18.449	18.460	18.471	18.482	18.493	18.504	1740
1750	18.504	18.515	18.526	18.536	18.547	18.558	18.569	18.580	18.591	18.602	18.612	1750
1760	18.612	18.623	18.634	18.645	18.655	18.666	18.677	18.687	18.698			1760

T/C Type S - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.14 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-60			-0.236	-0.233	-0.231	-0.229	-0.227	-0.225	-0.222	-0.220	-0.218	-60
-50	-0.218	-0.215	-0.213	-0.211	-0.209	-0.206	-0.204	-0.202	-0.199	-0.197	-0.194	-50
-40	-0.194	-0.192	-0.190	-0.187	-0.185	-0.182	-0.180	-0.178	-0.175	-0.173	-0.170	-40
-30	-0.170	-0.168	-0.165	-0.163	-0.160	-0.158	-0.155	-0.153	-0.150	-0.148	-0.145	-30
-20	-0.145	-0.142	-0.140	-0.137	-0.135	-0.132	-0.129	-0.127	-0.124	-0.122	-0.119	-20
-10	-0.119	-0.116	-0.114	-0.111	-0.108	-0.106	-0.103	-0.100	-0.097	-0.095	-0.092	-10
0	-0.092	-0.089	-0.086	-0.084	-0.081	-0.078	-0.075	-0.073	-0.070	-0.067	-0.064	0
10	-0.064	-0.061	-0.058	-0.056	-0.053	-0.050	-0.047	-0.044	-0.041	-0.038	-0.035	10
20	-0.035	-0.033	-0.030	-0.027	-0.024	-0.021	-0.018	-0.015	-0.012	-0.009	-0.006	20
30	-0.006	-0.003	0.000	0.003	0.006	0.009	0.012	0.015	0.018	0.021	0.024	30
40	0.024	0.027	0.030	0.033	0.037	0.040	0.043	0.046	0.049	0.052	0.055	40
50	0.055	0.058	0.062	0.065	0.068	0.071	0.074	0.077	0.081	0.084	0.087	50
60	0.087	0.090	0.093	0.097	0.100	0.103	0.106	0.110	0.113	0.116	0.119	60
70	0.119	0.123	0.126	0.129	0.133	0.136	0.139	0.142	0.146	0.149	0.152	70
80	0.152	0.156	0.159	0.163	0.166	0.169	0.173	0.176	0.179	0.183	0.186	80
90	0.186	0.190	0.193	0.197	0.200	0.203	0.207	0.210	0.214	0.217	0.221	90
100	0.221	0.224	0.228	0.231	0.235	0.238	0.242	0.245	0.249	0.252	0.256	100
110	0.256	0.259	0.263	0.266	0.270	0.274	0.277	0.281	0.284	0.288	0.291	110
120	0.291	0.295	0.299	0.302	0.306	0.309	0.313	0.317	0.320	0.324	0.328	120
130	0.328	0.331	0.335	0.339	0.342	0.346	0.350	0.353	0.357	0.361	0.365	130
140	0.365	0.368	0.372	0.376	0.379	0.383	0.387	0.391	0.394	0.398	0.402	140
150	0.402	0.406	0.409	0.413	0.417	0.421	0.425	0.428	0.432	0.436	0.440	150
160	0.440	0.444	0.448	0.451	0.455	0.459	0.463	0.467	0.471	0.474	0.478	160
170	0.478	0.482	0.486	0.490	0.494	0.498	0.502	0.506	0.510	0.513	0.517	170
180	0.517	0.521	0.525	0.529	0.533	0.537	0.541	0.545	0.549	0.553	0.557	180
190	0.557	0.561	0.565	0.569	0.573	0.577	0.581	0.585	0.589	0.593	0.597	190
200	0.597	0.601	0.605	0.609	0.613	0.617	0.621	0.625	0.629	0.633	0.637	200
210	0.637	0.641	0.645	0.649	0.653	0.658	0.662	0.666	0.670	0.674	0.678	210
220	0.678	0.682	0.686	0.690	0.695	0.699	0.703	0.707	0.711	0.715	0.719	220
230	0.719	0.724	0.728	0.732	0.736	0.740	0.744	0.749	0.753	0.757	0.761	230
240	0.761	0.765	0.770	0.774	0.778	0.782	0.786	0.791	0.795	0.799	0.803	240
250	0.803	0.808	0.812	0.816	0.820	0.824	0.829	0.833	0.837	0.842	0.846	250
260	0.846	0.850	0.854	0.859	0.863	0.867	0.872	0.876	0.880	0.884	0.889	260
270	0.889	0.893	0.897	0.902	0.906	0.910	0.915	0.919	0.923	0.928	0.932	270
280	0.932	0.936	0.941	0.945	0.950	0.954	0.958	0.963	0.967	0.971	0.976	280
290	0.976	0.980	0.985	0.989	0.993	0.998	1.002	1.007	1.011	1.015	1.020	290

Table 8.1.14 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
300	1.020	1.024	1.029	1.033	1.038	1.042	1.046	1.051	1.055	1.060	1.064	300
310	1.064	1.069	1.073	1.078	1.082	1.087	1.091	1.095	1.100	1.104	1.109	310
320	1.109	1.113	1.118	1.122	1.127	1.131	1.136	1.140	1.145	1.149	1.154	320
330	1.154	1.158	1.163	1.168	1.172	1.177	1.181	1.186	1.190	1.195	1.199	330
340	1.199	1.204	1.208	1.213	1.218	1.222	1.227	1.231	1.236	1.240	1.245	340
350	1.245	1.250	1.254	1.259	1.263	1.268	1.273	1.277	1.282	1.286	1.291	350
360	1.291	1.296	1.300	1.305	1.309	1.314	1.319	1.323	1.328	1.333	1.337	360
370	1.337	1.342	1.347	1.351	1.356	1.360	1.365	1.370	1.374	1.379	1.384	370
380	1.384	1.388	1.393	1.398	1.402	1.407	1.412	1.417	1.421	1.426	1.431	380
390	1.431	1.435	1.440	1.445	1.449	1.454	1.459	1.464	1.468	1.473	1.478	390
400	1.478	1.482	1.487	1.492	1.497	1.501	1.506	1.511	1.516	1.520	1.525	400
410	1.525	1.530	1.535	1.539	1.544	1.549	1.554	1.558	1.563	1.568	1.573	410
420	1.573	1.577	1.582	1.587	1.592	1.597	1.601	1.606	1.611	1.616	1.620	420
430	1.620	1.625	1.630	1.635	1.640	1.644	1.649	1.654	1.659	1.664	1.669	430
440	1.669	1.673	1.678	1.683	1.688	1.693	1.698	1.702	1.707	1.712	1.717	440
450	1.717	1.722	1.727	1.731	1.736	1.741	1.746	1.751	1.756	1.761	1.765	450
460	1.765	1.770	1.775	1.780	1.785	1.790	1.795	1.799	1.804	1.809	1.814	460
470	1.814	1.819	1.824	1.829	1.834	1.839	1.843	1.848	1.853	1.858	1.863	470
480	1.863	1.868	1.873	1.878	1.883	1.888	1.893	1.898	1.902	1.907	1.912	480
490	1.912	1.917	1.922	1.927	1.932	1.937	1.942	1.947	1.952	1.957	1.962	490
500	1.962	1.967	1.972	1.977	1.981	1.986	1.991	1.996	2.001	2.006	2.011	500
510	2.011	2.016	2.021	2.026	2.031	2.036	2.041	2.046	2.051	2.056	2.061	510
520	2.061	2.066	2.071	2.076	2.081	2.086	2.091	2.096	2.101	2.106	2.111	520
530	2.111	2.116	2.121	2.126	2.131	2.136	2.141	2.146	2.151	2.156	2.161	530
540	2.161	2.166	2.171	2.176	2.181	2.186	2.191	2.196	2.201	2.206	2.211	540
550	2.211	2.216	2.221	2.227	2.232	2.237	2.242	2.247	2.252	2.257	2.262	550
560	2.262	2.267	2.272	2.277	2.282	2.287	2.292	2.297	2.302	2.307	2.313	560
570	2.313	2.318	2.323	2.328	2.333	2.338	2.343	2.348	2.353	2.358	2.363	570
580	2.363	2.368	2.374	2.379	2.384	2.389	2.394	2.399	2.404	2.409	2.414	580
590	2.414	2.419	2.425	2.430	2.435	2.440	2.445	2.450	2.455	2.460	2.465	590
600	2.465	2.471	2.476	2.481	2.486	2.491	2.496	2.501	2.506	2.512	2.517	600
610	2.517	2.522	2.527	2.532	2.537	2.542	2.548	2.553	2.558	2.563	2.568	610
620	2.568	2.573	2.578	2.584	2.589	2.594	2.599	2.604	2.609	2.615	2.620	620
630	2.620	2.625	2.630	2.635	2.640	2.646	2.651	2.656	2.661	2.666	2.672	630
640	2.672	2.677	2.682	2.687	2.692	2.697	2.703	2.708	2.713	2.718	2.723	640
650	2.723	2.729	2.734	2.739	2.744	2.749	2.755	2.760	2.765	2.770	2.775	650
660	2.775	2.781	2.786	2.791	2.796	2.801	2.807	2.812	2.817	2.822	2.828	660
670	2.828	2.833	2.838	2.843	2.848	2.854	2.859	2.864	2.869	2.875	2.880	670
680	2.880	2.885	2.890	2.895	2.901	2.906	2.911	2.916	2.922	2.927	2.932	680
690	2.932	2.937	2.943	2.948	2.953	2.958	2.964	2.969	2.974	2.979	2.985	690
700	2.985	2.990	2.995	3.000	3.006	3.011	3.016	3.022	3.027	3.032	3.037	700
710	3.037	3.043	3.048	3.053	3.058	3.064	3.069	3.074	3.080	3.085	3.090	710
720	3.090	3.095	3.101	3.106	3.111	3.117	3.122	3.127	3.132	3.138	3.143	720
730	3.143	3.148	3.154	3.159	3.164	3.169	3.175	3.180	3.185	3.191	3.196	730
740	3.196	3.201	3.207	3.212	3.217	3.223	3.228	3.233	3.238	3.244	3.249	740
750	3.249	3.254	3.260	3.265	3.270	3.276	3.281	3.286	3.292	3.297	3.302	750
760	3.302	3.308	3.313	3.318	3.324	3.329	3.334	3.340	3.345	3.350	3.356	760
770	3.356	3.361	3.366	3.372	3.377	3.382	3.388	3.393	3.398	3.404	3.409	770
780	3.409	3.414	3.420	3.425	3.430	3.436	3.441	3.447	3.452	3.457	3.463	780
790	3.463	3.468	3.473	3.479	3.484	3.489	3.495	3.500	3.506	3.511	3.516	790
800	3.516	3.522	3.527	3.532	3.538	3.543	3.549	3.554	3.559	3.565	3.570	800
810	3.570	3.575	3.581	3.586	3.592	3.597	3.602	3.608	3.613	3.619	3.624	810
820	3.624	3.629	3.635	3.640	3.645	3.651	3.656	3.662	3.667	3.672	3.678	820

Table 8.1.14 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
830	3.678	3.683	3.689	3.694	3.699	3.705	3.710	3.716	3.721	3.726	3.732	830
840	3.732	3.737	3.743	3.748	3.754	3.759	3.764	3.770	3.775	3.781	3.786	840
850	3.786	3.791	3.797	3.802	3.808	3.813	3.819	3.824	3.829	3.835	3.840	850
860	3.840	3.846	3.851	3.857	3.862	3.867	3.873	3.878	3.884	3.889	3.895	860
870	3.895	3.900	3.906	3.911	3.916	3.922	3.927	3.933	3.938	3.944	3.949	870
880	3.949	3.955	3.960	3.965	3.971	3.976	3.982	3.987	3.993	3.998	4.004	880
890	4.004	4.009	4.015	4.020	4.025	4.031	4.036	4.042	4.047	4.053	4.058	890
900	4.058	4.064	4.069	4.075	4.080	4.086	4.091	4.096	4.102	4.107	4.113	900
910	4.113	4.118	4.124	4.129	4.135	4.140	4.146	4.151	4.157	4.162	4.168	910
920	4.168	4.173	4.179	4.184	4.190	4.195	4.201	4.206	4.212	4.217	4.223	920
930	4.223	4.228	4.234	4.239	4.245	4.250	4.256	4.261	4.267	4.272	4.278	930
940	4.278	4.283	4.289	4.294	4.300	4.305	4.311	4.316	4.322	4.327	4.333	940
950	4.333	4.338	4.344	4.349	4.355	4.360	4.366	4.371	4.377	4.382	4.388	950
960	4.388	4.393	4.399	4.404	4.410	4.415	4.421	4.426	4.432	4.438	4.443	960
970	4.443	4.449	4.454	4.460	4.465	4.471	4.476	4.482	4.487	4.493	4.498	970
980	4.498	4.504	4.509	4.515	4.521	4.526	4.532	4.537	4.543	4.548	4.554	980
990	4.554	4.559	4.565	4.570	4.576	4.582	4.587	4.593	4.598	4.604	4.609	990
1000	4.609	4.615	4.620	4.626	4.632	4.637	4.643	4.648	4.654	4.659	4.665	1000
1010	4.665	4.670	4.676	4.682	4.687	4.693	4.698	4.704	4.709	4.715	4.721	1010
1020	4.721	4.726	4.732	4.737	4.743	4.748	4.754	4.760	4.765	4.771	4.776	1020
1030	4.776	4.782	4.788	4.793	4.799	4.804	4.810	4.815	4.821	4.827	4.832	1030
1040	4.832	4.838	4.843	4.849	4.855	4.860	4.866	4.871	4.877	4.883	4.888	1040
1050	4.888	4.894	4.899	4.905	4.911	4.916	4.922	4.927	4.933	4.939	4.944	1050
1060	4.944	4.950	4.956	4.961	4.967	4.972	4.978	4.984	4.989	4.995	5.000	1060
1070	5.000	5.006	5.012	5.017	5.023	5.029	5.034	5.040	5.045	5.051	5.057	1070
1080	5.057	5.062	5.068	5.074	5.079	5.085	5.090	5.096	5.102	5.107	5.113	1080
1090	5.113	5.119	5.124	5.130	5.136	5.141	5.147	5.153	5.158	5.164	5.169	1090
1100	5.169	5.175	5.181	5.186	5.192	5.198	5.203	5.209	5.215	5.220	5.226	1100
1110	5.226	5.232	5.237	5.243	5.249	5.254	5.260	5.266	5.271	5.277	5.283	1110
1120	5.283	5.288	5.294	5.300	5.305	5.311	5.317	5.322	5.328	5.334	5.339	1120
1130	5.339	5.345	5.351	5.356	5.362	5.368	5.373	5.379	5.385	5.391	5.396	1130
1140	5.396	5.402	5.408	5.413	5.419	5.425	5.430	5.436	5.442	5.447	5.453	1140
1150	5.453	5.459	5.465	5.470	5.476	5.482	5.487	5.493	5.499	5.504	5.510	1150
1160	5.510	5.516	5.522	5.527	5.533	5.539	5.544	5.550	5.556	5.562	5.567	1160
1170	5.567	5.573	5.579	5.585	5.590	5.596	5.602	5.608	5.613	5.619	5.625	1170
1180	5.625	5.631	5.636	5.642	5.648	5.653	5.659	5.665	5.671	5.676	5.682	1180
1190	5.682	5.688	5.694	5.700	5.705	5.711	5.717	5.723	5.728	5.734	5.740	1190
1200	5.740	5.746	5.751	5.757	5.763	5.769	5.774	5.780	5.786	5.792	5.797	1200
1210	5.797	5.803	5.809	5.815	5.821	5.826	5.832	5.838	5.844	5.849	5.855	1210
1220	5.855	5.861	5.867	5.873	5.878	5.884	5.890	5.896	5.902	5.907	5.913	1220
1230	5.913	5.919	5.925	5.931	5.936	5.942	5.948	5.954	5.960	5.965	5.971	1230
1240	5.971	5.977	5.983	5.989	5.994	6.000	6.006	6.012	6.018	6.023	6.029	1240
1250	6.029	6.035	6.041	6.047	6.052	6.058	6.064	6.070	6.076	6.082	6.087	1250
1260	6.087	6.093	6.099	6.105	6.111	6.117	6.122	6.128	6.134	6.140	6.146	1260
1270	6.146	6.152	6.157	6.163	6.169	6.175	6.181	6.187	6.192	6.198	6.204	1270
1280	6.204	6.210	6.216	6.222	6.227	6.233	6.239	6.245	6.251	6.257	6.263	1280
1290	6.263	6.268	6.274	6.280	6.286	6.292	6.298	6.304	6.309	6.315	6.321	1290
1300	6.321	6.327	6.333	6.339	6.345	6.350	6.356	6.362	6.368	6.374	6.380	1300
1310	6.380	6.386	6.392	6.397	6.403	6.409	6.415	6.421	6.427	6.433	6.439	1310
1320	6.439	6.445	6.450	6.456	6.462	6.468	6.474	6.480	6.486	6.492	6.498	1320
1330	6.498	6.503	6.509	6.515	6.521	6.527	6.533	6.539	6.545	6.551	6.557	1330
1340	6.557	6.562	6.568	6.574	6.580	6.586	6.592	6.598	6.604	6.610	6.616	1340
1350	6.616	6.622	6.627	6.633	6.639	6.645	6.651	6.657	6.663	6.669	6.675	1350

Table 8.1.14 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1360	6.675	6.681	6.687	6.693	6.699	6.704	6.710	6.716	6.722	6.728	6.734	1360
1370	6.734	6.740	6.746	6.752	6.758	6.764	6.770	6.776	6.782	6.788	6.794	1370
1380	6.794	6.800	6.805	6.811	6.817	6.823	6.829	6.835	6.841	6.847	6.853	1380
1390	6.853	6.859	6.865	6.871	6.877	6.883	6.889	6.895	6.901	6.907	6.913	1390
1400	6.913	6.919	6.925	6.931	6.937	6.943	6.948	6.954	6.960	6.966	6.972	1400
1410	6.972	6.978	6.984	6.990	6.996	7.002	7.008	7.014	7.020	7.026	7.032	1410
1420	7.032	7.038	7.044	7.050	7.056	7.062	7.068	7.074	7.080	7.086	7.092	1420
1430	7.092	7.098	7.104	7.110	7.116	7.122	7.128	7.134	7.140	7.146	7.152	1430
1440	7.152	7.158	7.164	7.170	7.176	7.182	7.188	7.194	7.200	7.206	7.212	1440
1450	7.212	7.218	7.224	7.230	7.236	7.242	7.248	7.254	7.260	7.266	7.272	1450
1460	7.272	7.278	7.285	7.291	7.297	7.303	7.309	7.315	7.321	7.327	7.333	1460
1470	7.333	7.339	7.345	7.351	7.357	7.363	7.369	7.375	7.381	7.387	7.393	1470
1480	7.393	7.399	7.405	7.411	7.417	7.423	7.429	7.436	7.442	7.448	7.454	1480
1490	7.454	7.460	7.466	7.472	7.478	7.484	7.490	7.496	7.502	7.508	7.514	1490
1500	7.514	7.520	7.526	7.533	7.539	7.545	7.551	7.557	7.563	7.569	7.575	1500
1510	7.575	7.581	7.587	7.593	7.599	7.605	7.612	7.618	7.624	7.630	7.636	1510
1520	7.636	7.642	7.648	7.654	7.660	7.666	7.672	7.679	7.685	7.691	7.697	1520
1530	7.697	7.703	7.709	7.715	7.721	7.727	7.733	7.740	7.746	7.752	7.758	1530
1540	7.758	7.764	7.770	7.776	7.782	7.788	7.795	7.801	7.807	7.813	7.819	1540
1550	7.819	7.825	7.831	7.837	7.843	7.850	7.856	7.862	7.868	7.874	7.880	1550
1560	7.880	7.886	7.892	7.899	7.905	7.911	7.917	7.923	7.929	7.935	7.942	1560
1570	7.942	7.948	7.954	7.960	7.966	7.972	7.978	7.985	7.991	7.997	8.003	1570
1580	8.003	8.009	8.015	8.021	8.028	8.034	8.040	8.046	8.052	8.058	8.065	1580
1590	8.065	8.071	8.077	8.083	8.089	8.095	8.101	8.108	8.114	8.120	8.126	1590
1600	8.126	8.132	8.138	8.145	8.151	8.157	8.163	8.169	8.176	8.182	8.188	1600
1610	8.188	8.194	8.200	8.206	8.213	8.219	8.225	8.231	8.237	8.244	8.250	1610
1620	8.250	8.256	8.262	8.268	8.275	8.281	8.287	8.293	8.299	8.305	8.312	1620
1630	8.312	8.318	8.324	8.330	8.336	8.343	8.349	8.355	8.361	8.368	8.374	1630
1640	8.374	8.380	8.386	8.392	8.399	8.405	8.411	8.417	8.423	8.430	8.436	1640
1650	8.436	8.442	8.448	8.455	8.461	8.467	8.473	8.479	8.486	8.492	8.498	1650
1660	8.498	8.504	8.511	8.517	8.523	8.529	8.536	8.542	8.548	8.554	8.560	1660
1670	8.560	8.567	8.573	8.579	8.585	8.592	8.598	8.604	8.610	8.617	8.623	1670
1680	8.623	8.629	8.635	8.642	8.648	8.654	8.660	8.667	8.673	8.679	8.685	1680
1690	8.685	8.692	8.698	8.704	8.711	8.717	8.723	8.729	8.736	8.742	8.748	1690
1700	8.748	8.754	8.761	8.767	8.773	8.780	8.786	8.792	8.798	8.805	8.811	1700
1710	8.811	8.817	8.823	8.830	8.836	8.842	8.849	8.855	8.861	8.867	8.874	1710
1720	8.874	8.880	8.886	8.893	8.899	8.905	8.912	8.918	8.924	8.930	8.937	1720
1730	8.937	8.943	8.949	8.956	8.962	8.968	8.975	8.981	8.987	8.993	9.000	1730
1740	9.000	9.006	9.012	9.019	9.025	9.031	9.038	9.044	9.050	9.057	9.063	1740
1750	9.063	9.069	9.076	9.082	9.088	9.095	9.101	9.107	9.114	9.120	9.126	1750
1760	9.126	9.133	9.139	9.145	9.152	9.158	9.164	9.171	9.177	9.183	9.190	1760
1770	9.190	9.196	9.202	9.209	9.215	9.221	9.228	9.234	9.240	9.247	9.253	1770
1780	9.253	9.259	9.266	9.272	9.278	9.285	9.291	9.298	9.304	9.310	9.317	1780
1790	9.317	9.323	9.329	9.336	9.342	9.348	9.355	9.361	9.368	9.374	9.380	1790
1800	9.380	9.387	9.393	9.399	9.406	9.412	9.419	9.425	9.431	9.438	9.444	1800
1810	9.444	9.450	9.457	9.463	9.470	9.476	9.482	9.489	9.495	9.502	9.508	1810
1820	9.508	9.514	9.521	9.527	9.533	9.540	9.546	9.553	9.559	9.565	9.572	1820
1830	9.572	9.578	9.585	9.591	9.598	9.604	9.610	9.617	9.623	9.630	9.636	1830
1840	9.636	9.642	9.649	9.655	9.662	9.668	9.674	9.681	9.687	9.694	9.700	1840
1850	9.700	9.707	9.713	9.719	9.726	9.732	9.739	9.745	9.752	9.758	9.764	1850
1860	9.764	9.771	9.777	9.784	9.790	9.797	9.803	9.809	9.816	9.822	9.829	1860
1870	9.829	9.835	9.842	9.848	9.855	9.861	9.867	9.874	9.880	9.887	9.893	1870
1880	9.893	9.900	9.906	9.913	9.919	9.926	9.932	9.938	9.945	9.951	9.958	1880

Table 8.1.14 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1890	9.958	9.964	9.971	9.977	9.984	9.990	9.997	10.003	10.010	10.016	10.023	1890
1900	10.023	10.029	10.036	10.042	10.048	10.055	10.061	10.068	10.074	10.081	10.087	1900
1910	10.087	10.094	10.100	10.107	10.113	10.120	10.126	10.133	10.139	10.146	10.152	1910
1920	10.152	10.159	10.165	10.172	10.178	10.185	10.191	10.198	10.204	10.211	10.217	1920
1930	10.217	10.224	10.230	10.237	10.243	10.250	10.256	10.263	10.269	10.276	10.282	1930
1940	10.282	10.289	10.295	10.302	10.308	10.315	10.321	10.328	10.334	10.341	10.348	1940
1950	10.348	10.354	10.361	10.367	10.374	10.380	10.387	10.393	10.400	10.406	10.413	1950
1960	10.413	10.419	10.426	10.432	10.439	10.445	10.452	10.459	10.465	10.472	10.478	1960
1970	10.478	10.485	10.491	10.498	10.504	10.511	10.517	10.524	10.531	10.537	10.544	1970
1980	10.544	10.550	10.557	10.563	10.570	10.576	10.583	10.589	10.596	10.603	10.609	1980
1990	10.609	10.616	10.622	10.629	10.635	10.642	10.648	10.655	10.662	10.668	10.675	1990
2000	10.675	10.681	10.688	10.694	10.701	10.708	10.714	10.721	10.727	10.734	10.740	2000
2010	10.740	10.747	10.754	10.760	10.767	10.773	10.780	10.786	10.793	10.800	10.806	2010
2020	10.806	10.813	10.819	10.826	10.832	10.839	10.846	10.852	10.859	10.865	10.872	2020
2030	10.872	10.879	10.885	10.892	10.898	10.905	10.912	10.918	10.925	10.931	10.938	2030
2040	10.938	10.944	10.951	10.958	10.964	10.971	10.977	10.984	10.991	10.997	11.004	2040
2050	11.004	11.010	11.017	11.024	11.030	11.037	11.043	11.050	11.057	11.063	11.070	2050
2060	11.070	11.076	11.083	11.090	11.096	11.103	11.110	11.116	11.123	11.129	11.136	2060
2070	11.136	11.143	11.149	11.156	11.162	11.169	11.176	11.182	11.189	11.196	11.202	2070
2080	11.202	11.209	11.215	11.222	11.229	11.235	11.242	11.248	11.255	11.262	11.268	2080
2090	11.268	11.275	11.282	11.288	11.295	11.301	11.308	11.315	11.321	11.328	11.335	2090
32100	11.335	11.341	11.348	11.355	11.361	11.368	11.374	11.381	11.388	11.394	11.401	32100
2110	11.401	11.408	11.414	11.421	11.428	11.434	11.441	11.447	11.454	11.461	11.467	2110
2120	11.467	11.474	11.481	11.487	11.494	11.501	11.507	11.514	11.521	11.527	11.534	2120
2130	11.534	11.541	11.547	11.554	11.560	11.567	11.574	11.580	11.587	11.594	11.600	2130
2140	11.600	11.607	11.614	11.620	11.627	11.634	11.640	11.647	11.654	11.660	11.667	2140
2150	11.667	11.674	11.680	11.687	11.694	11.700	11.707	11.714	11.720	11.727	11.734	2150
2160	11.734	11.740	11.747	11.754	11.760	11.767	11.774	11.780	11.787	11.794	11.800	2160
2170	11.800	11.807	11.814	11.820	11.827	11.834	11.840	11.847	11.854	11.860	11.867	2170
2180	11.867	11.874	11.880	11.887	11.894	11.900	11.907	11.914	11.920	11.927	11.934	2180
2190	11.934	11.940	11.947	11.954	11.960	11.967	11.974	11.980	11.987	11.994	12.001	2190
2200	12.001	12.007	12.014	12.021	12.027	12.034	12.041	12.047	12.054	12.061	12.067	2200
2210	12.067	12.074	12.081	12.087	12.094	12.101	12.107	12.114	12.121	12.128	12.134	2210
2220	12.134	12.141	12.148	12.154	12.161	12.168	12.174	12.181	12.188	12.194	12.201	2220
2230	12.201	12.208	12.215	12.221	12.228	12.235	12.241	12.248	12.255	12.261	12.268	2230
2240	12.268	12.275	12.282	12.288	12.295	12.302	12.308	12.315	12.322	12.328	12.335	2240
2250	12.335	12.342	12.349	12.355	12.362	12.369	12.375	12.382	12.389	12.395	12.402	2250
2260	12.402	12.409	12.416	12.422	12.429	12.436	12.442	12.449	12.456	12.463	12.469	2260
2270	12.469	12.476	12.483	12.489	12.496	12.503	12.510	12.516	12.523	12.530	12.536	2270
2280	12.536	12.543	12.550	12.557	12.563	12.570	12.577	12.583	12.590	12.597	12.604	2280
2290	12.604	12.610	12.617	12.624	12.630	12.637	12.644	12.651	12.657	12.664	12.671	2290
2300	12.671	12.677	12.684	12.691	12.698	12.704	12.711	12.718	12.724	12.731	12.738	2300
2310	12.738	12.745	12.751	12.758	12.765	12.771	12.778	12.785	12.792	12.798	12.805	2310
2320	12.805	12.812	12.819	12.825	12.832	12.839	12.845	12.852	12.859	12.866	12.872	2320
2330	12.872	12.879	12.886	12.893	12.899	12.906	12.913	12.919	12.926	12.933	12.940	2330
2340	12.940	12.946	12.953	12.960	12.967	12.973	12.980	12.987	12.993	13.000	13.007	2340
2350	13.007	13.014	13.020	13.027	13.034	13.041	13.047	13.054	13.061	13.067	13.074	2350
2360	13.074	13.081	13.088	13.094	13.101	13.108	13.115	13.121	13.128	13.135	13.142	2360
2370	13.142	13.148	13.155	13.162	13.168	13.175	13.182	13.189	13.195	13.202	13.209	2370
2380	13.209	13.216	13.222	13.229	13.236	13.243	13.249	13.256	13.263	13.269	13.276	2380
2390	13.276	13.283	13.290	13.296	13.303	13.310	13.317	13.323	13.330	13.337	13.344	2390
2400	13.344	13.350	13.357	13.364	13.371	13.377	13.384	13.391	13.397	13.404	13.411	2400
2410	13.411	13.418	13.424	13.431	13.438	13.445	13.451	13.458	13.465	13.472	13.478	2410

Table 8.1.14 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2420	13.478	13.485	13.492	13.499	13.505	13.512	13.519	13.526	13.532	13.539	13.546	2420
2430	13.546	13.552	13.559	13.566	13.573	13.579	13.586	13.593	13.600	13.606	13.613	2430
2440	13.613	13.620	13.627	13.633	13.640	13.647	13.654	13.660	13.667	13.674	13.681	2440
2450	13.681	13.687	13.694	13.701	13.708	13.714	13.721	13.728	13.734	13.741	13.748	2450
2460	13.748	13.755	13.761	13.768	13.775	13.782	13.788	13.795	13.802	13.809	13.815	2460
2470	13.815	13.822	13.829	13.836	13.842	13.849	13.856	13.863	13.869	13.876	13.883	2470
2480	13.883	13.890	13.896	13.903	13.910	13.916	13.923	13.930	13.937	13.943	13.950	2480
2490	13.950	13.957	13.964	13.970	13.977	13.984	13.991	13.997	14.004	14.011	14.018	2490
2500	14.018	14.024	14.031	14.038	14.045	14.051	14.058	14.065	14.072	14.078	14.085	2500
2510	14.085	14.092	14.098	14.105	14.112	14.119	14.125	14.132	14.139	14.146	14.152	2510
2520	14.152	14.159	14.166	14.173	14.179	14.186	14.193	14.200	14.206	14.213	14.220	2520
2530	14.220	14.226	14.233	14.240	14.247	14.253	14.260	14.267	14.274	14.280	14.287	2530
2540	14.287	14.294	14.301	14.307	14.314	14.321	14.328	14.334	14.341	14.348	14.354	2540
2550	14.354	14.361	14.368	14.375	14.381	14.388	14.395	14.402	14.408	14.415	14.422	2550
2560	14.422	14.429	14.435	14.442	14.449	14.455	14.462	14.469	14.476	14.482	14.489	2560
2570	14.489	14.496	14.503	14.509	14.516	14.523	14.530	14.536	14.543	14.550	14.556	2570
2580	14.556	14.563	14.570	14.577	14.583	14.590	14.597	14.604	14.610	14.617	14.624	2580
2590	14.624	14.631	14.637	14.644	14.651	14.657	14.664	14.671	14.678	14.684	14.691	2590
2600	14.691	14.698	14.705	14.711	14.718	14.725	14.731	14.738	14.745	14.752	14.758	2600
2610	14.758	14.765	14.772	14.778	14.785	14.792	14.799	14.805	14.812	14.819	14.826	2610
2620	14.826	14.832	14.839	14.846	14.852	14.859	14.866	14.873	14.879	14.886	14.893	2620
2630	14.893	14.899	14.906	14.913	14.920	14.926	14.933	14.940	14.946	14.953	14.960	2630
2640	14.960	14.967	14.973	14.980	14.987	14.994	15.000	15.007	15.014	15.020	15.027	2640
2650	15.027	15.034	15.041	15.047	15.054	15.061	15.067	15.074	15.081	15.088	15.094	2650
2660	15.094	15.101	15.108	15.114	15.121	15.128	15.134	15.141	15.148	15.155	15.161	2660
2670	15.161	15.168	15.175	15.181	15.188	15.195	15.202	15.208	15.215	15.222	15.228	2670
2680	15.228	15.235	15.242	15.248	15.255	15.262	15.269	15.275	15.282	15.289	15.295	2680
2690	15.295	15.302	15.309	15.315	15.322	15.329	15.336	15.342	15.349	15.356	15.362	2690
2700	15.362	15.369	15.376	15.382	15.389	15.396	15.403	15.409	15.416	15.423	15.429	2700
2710	15.429	15.436	15.443	15.449	15.456	15.463	15.469	15.476	15.483	15.490	15.496	2710
2720	15.496	15.503	15.510	15.516	15.523	15.530	15.536	15.543	15.550	15.556	15.563	2720
2730	15.563	15.570	15.576	15.583	15.590	15.597	15.603	15.610	15.617	15.623	15.630	2730
2740	15.630	15.637	15.643	15.650	15.657	15.663	15.670	15.677	15.683	15.690	15.697	2740
2750	15.697	15.703	15.710	15.717	15.723	15.730	15.737	15.743	15.750	15.757	15.763	2750
2760	15.763	15.770	15.777	15.783	15.790	15.797	15.804	15.810	15.817	15.824	15.830	2760
2770	15.830	15.837	15.844	15.850	15.857	15.864	15.870	15.877	15.883	15.890	15.897	2770
2780	15.897	15.903	15.910	15.917	15.923	15.930	15.937	15.943	15.950	15.957	15.963	2780
2790	15.963	15.970	15.977	15.983	15.990	15.997	16.003	16.010	16.017	16.023	16.030	2790
2800	16.030	16.037	16.043	16.050	16.057	16.063	16.070	16.077	16.083	16.090	16.096	2800
2810	16.096	16.103	16.110	16.116	16.123	16.130	16.136	16.143	16.150	16.156	16.163	2810
2820	16.163	16.170	16.176	16.183	16.189	16.196	16.203	16.209	16.216	16.223	16.229	2820
2830	16.229	16.236	16.243	16.249	16.256	16.262	16.269	16.276	16.282	16.289	16.296	2830
2840	16.296	16.302	16.309	16.315	16.322	16.329	16.335	16.342	16.349	16.355	16.362	2840
2850	16.362	16.368	16.375	16.382	16.388	16.395	16.402	16.408	16.415	16.421	16.428	2850
2860	16.428	16.435	16.441	16.448	16.454	16.461	16.468	16.474	16.481	16.488	16.494	2860
2870	16.494	16.501	16.507	16.514	16.521	16.527	16.534	16.540	16.547	16.554	16.560	2870
2880	16.560	16.567	16.573	16.580	16.587	16.593	16.600	16.606	16.613	16.620	16.626	2880
2890	16.626	16.633	16.639	16.646	16.653	16.659	16.666	16.672	16.679	16.686	16.692	2890
2900	16.692	16.699	16.705	16.712	16.719	16.725	16.732	16.738	16.745	16.751	16.758	2900
2910	16.758	16.765	16.771	16.778	16.784	16.791	16.797	16.804	16.811	16.817	16.824	2910
2920	16.824	16.830	16.837	16.844	16.850	16.857	16.863	16.870	16.876	16.883	16.890	2920
2930	16.890	16.896	16.903	16.909	16.916	16.922	16.929	16.935	16.942	16.949	16.955	2930
2940	16.955	16.962	16.968	16.975	16.981	16.988	16.995	17.001	17.008	17.014	17.021	2940

Table 8.1.14 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
2950	17.021	17.027	17.034	17.040	17.047	17.053	17.060	17.067	17.073	17.080	17.086	2950
2960	17.086	17.093	17.099	17.106	17.112	17.119	17.125	17.132	17.139	17.145	17.152	2960
2970	17.152	17.158	17.165	17.171	17.178	17.184	17.191	17.197	17.204	17.210	17.217	2970
2980	17.217	17.223	17.230	17.237	17.243	17.250	17.256	17.263	17.269	17.276	17.282	2980
2990	17.282	17.289	17.295	17.302	17.308	17.315	17.321	17.328	17.334	17.341	17.347	2990
3000	17.347	17.354	17.360	17.367	17.373	17.380	17.386	17.393	17.399	17.406	17.412	3000
3010	17.412	17.419	17.425	17.432	17.438	17.445	17.451	17.458	17.464	17.471	17.477	3010
3020	17.477	17.484	17.490	17.497	17.503	17.510	17.516	17.523	17.529	17.536	17.542	3020
3030	17.542	17.549	17.555	17.562	17.568	17.575	17.581	17.588	17.594	17.601	17.607	3030
3040	17.607	17.614	17.620	17.627	17.633	17.639	17.646	17.652	17.659	17.665	17.672	3040
3050	17.672	17.678	17.685	17.691	17.698	17.704	17.711	17.717	17.723	17.730	17.736	3050
3060	17.736	17.743	17.749	17.756	17.762	17.769	17.775	17.781	17.788	17.794	17.801	3060
3070	17.801	17.807	17.814	17.820	17.826	17.833	17.839	17.846	17.852	17.859	17.865	3070
3080	17.865	17.871	17.878	17.884	17.891	17.897	17.903	17.910	17.916	17.923	17.929	3080
3090	17.929	17.935	17.942	17.948	17.954	17.961	17.967	17.974	17.980	17.986	17.993	3090
3100	17.993	17.999	18.005	18.012	18.018	18.024	18.031	18.037	18.043	18.050	18.056	3100
3110	18.056	18.063	18.069	18.075	18.081	18.088	18.094	18.100	18.107	18.113	18.119	3110
3120	18.119	18.126	18.132	18.138	18.145	18.151	18.157	18.163	18.170	18.176	18.182	3120
3130	18.182	18.189	18.195	18.201	18.207	18.214	18.220	18.226	18.232	18.239	18.245	3130
3140	18.245	18.251	18.257	18.264	18.270	18.276	18.282	18.289	18.295	18.301	18.307	3140
3150	18.307	18.313	18.320	18.326	18.332	18.338	18.344	18.351	18.357	18.363	18.369	3150
3160	18.369	18.375	18.381	18.388	18.394	18.400	18.406	18.412	18.418	18.424	18.431	3160
3170	18.431	18.437	18.443	18.449	18.455	18.461	18.467	18.473	18.479	18.486	18.492	3170
3180	18.492	18.498	18.504	18.510	18.516	18.522	18.528	18.534	18.540	18.546	18.552	3180
3190	18.552	18.558	18.564	18.570	18.576	18.582	18.588	18.594	18.600	18.606	18.612	3190
3200	18.612	18.618	18.624	18.630	18.636	18.642	18.648	18.654	18.660	18.666	18.672	3200
3210	18.672	18.678	18.684	18.690	18.696							3210

T/C Type T - Thermoelectric Voltage

As a Function of Temperature (°C) Reference Junctions at 0 °C
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.15 Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-270	-6.258	-6.256	-6.255	-6.253	-6.251	-6.248	-6.245	-6.242	-6.239	-6.236	-6.232	-270
-260	-6.232	-6.228	-6.224	-6.219	-6.214	-6.209	-6.204	-6.198	-6.193	-6.187	-6.181	-260
-250	-6.181	-6.174	-6.167	-6.160	-6.153	-6.146	-6.138	-6.130	-6.122	-6.114	-6.105	-250
-240	-6.105	-6.096	-6.087	-6.078	-6.068	-6.059	-6.049	-6.039	-6.028	-6.018	-6.007	-240
-230	-6.007	-5.996	-5.985	-5.973	-5.962	-5.950	-5.938	-5.926	-5.914	-5.901	-5.889	-230
-220	-5.889	-5.876	-5.863	-5.850	-5.836	-5.823	-5.509	-5.795	-5.782	-5.767	-5.753	-220
-210	-5.753	-5.739	-5.724	-5.710	-5.695	-5.680	-5.665	-5.650	-5.634	-5.619	-5.603	-210
-200	-5.603	-5.587	-5.571	-5.555	-5.539	-5.522	-5.506	-5.489	-5.473	-5.456	-5.439	-200
-190	-5.439	-5.421	-5.404	-5.387	-5.369	-5.351	-5.333	-5.315	-5.297	-5.279	-5.261	-190
-180	-5.261	-5.242	-5.223	-5.205	-5.186	-5.167	-5.147	-5.128	-5.109	-5.089	-5.069	-180
-170	-5.069	-5.050	-5.030	-5.010	-4.989	-4.969	-4.948	-4.928	-4.907	-4.886	-4.865	-170
-160	-4.865	-4.844	-4.823	-4.801	-4.780	-4.758	-4.737	-4.715	-4.693	-4.670	-4.648	-160
-150	-4.648	-4.626	-4.603	-4.581	-4.558	-4.535	-4.512	-4.489	-4.466	-4.442	-4.419	-150
-140	-4.419	-4.395	-4.371	-4.347	-4.323	-4.299	-4.275	-4.251	-4.226	-4.202	-4.177	-140
-130	-4.177	-4.152	-4.127	-4.102	-4.077	-4.051	-4.026	-4.000	-3.974	-3.949	-3.923	-130
-120	-3.923	-3.897	-3.870	-3.844	-3.818	-3.791	-3.764	-3.737	-3.711	-3.684	-3.656	-120
-110	-3.656	-3.629	-3.602	-3.574	-3.547	-3.519	-3.491	-3.463	-3.435	-3.407	-3.378	-110

Table 8.1.15 cont. Thermoelectric Voltage in Absolute Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-100	-3.378	-3.350	-3.321	-3.293	-3.264	-3.235	-3.206	-3.177	-3.147	-3.118	-3.089	-100
-90	-3.089	-3.059	-3.029	-2.999	-2.970	-2.939	-2.909	-2.879	-2.849	-2.818	-2.788	-90
-80	-2.788	-2.757	-2.726	-2.695	-2.664	-2.633	-2.602	-2.570	-2.539	-2.507	-2.475	-80
-70	-2.475	-2.444	-2.412	-2.380	-2.348	-2.315	-2.283	-2.250	-2.218	-2.185	-2.152	-70
-60	-2.152	-2.120	-2.087	-2.053	-2.020	-1.987	-1.953	-1.920	-1.886	-1.853	-1.819	-60
-50	-1.819	-1.785	-1.751	-1.717	-1.682	-1.648	-1.614	-1.579	-1.544	-1.510	-1.475	-50
-40	-1.475	-1.440	-1.405	-1.370	-1.334	-1.299	-1.263	-1.228	-1.192	-1.157	-1.121	-40
-30	-1.121	-1.085	-1.049	-1.013	-0.976	-0.940	-0.903	-0.867	-0.830	-0.794	-0.757	-30
-20	-0.757	-0.720	-0.683	-0.646	-0.608	-0.571	-0.534	-0.496	-0.458	-0.421	-0.383	-20
-10	-0.383	-0.345	-0.307	-0.269	-0.231	-0.193	-0.154	-0.116	-0.077	-0.039	0.000	-10
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.351	0.391	0
10	0.391	0.430	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.789	10
20	0.789	0.830	0.870	0.911	0.951	0.992	1.032	1.073	1.114	1.155	1.196	20
30	1.196	1.237	1.279	1.320	1.361	1.403	1.444	1.486	1.528	1.569	1.611	30
40	1.611	1.653	1.695	1.738	1.780	1.822	1.865	1.907	1.950	1.992	2.035	40
50	2.035	2.078	2.121	2.164	2.207	2.250	2.294	2.337	2.380	2.424	2.467	50
60	2.467	2.511	2.555	2.599	2.643	2.687	2.731	2.775	2.819	2.864	2.908	60
70	2.908	2.953	2.997	3.042	3.087	3.131	3.176	3.221	3.266	3.312	3.357	70
80	3.357	3.402	3.447	3.493	3.538	3.584	3.630	3.676	3.721	3.767	3.813	80
90	3.813	3.859	3.906	3.952	3.998	4.044	4.091	4.137	4.184	4.231	4.277	90
100	4.277	4.324	4.371	4.418	4.465	4.512	4.559	4.607	4.654	4.701	4.749	100
110	4.749	4.796	4.844	4.891	4.939	4.987	5.035	5.083	5.131	5.179	5.227	110
120	5.227	5.275	5.324	5.372	5.420	5.469	5.517	5.566	5.615	5.663	5.712	120
130	5.712	5.761	5.810	5.859	5.908	5.957	6.007	6.056	6.105	6.155	6.204	130
140	6.204	6.254	6.303	6.353	6.403	6.452	6.502	6.552	6.602	6.652	6.702	140
150	6.702	6.753	6.803	6.853	6.903	6.954	7.004	7.055	7.106	7.156	7.207	150
160	7.207	7.258	7.309	7.360	7.411	7.462	7.513	7.564	7.615	7.666	7.718	160
170	7.718	7.769	7.821	7.872	7.924	7.975	8.027	8.079	8.131	8.183	8.235	170
180	8.235	8.287	8.339	8.391	8.443	8.495	8.548	8.600	8.652	8.705	8.757	180
190	8.757	8.810	8.863	8.915	8.968	9.021	9.074	9.127	9.180	9.233	9.286	190
200	9.286	9.339	9.392	9.446	9.499	9.553	9.606	9.659	9.713	9.767	9.820	200
210	9.820	9.874	9.928	9.982	10.036	10.090	10.144	10.198	10.252	10.306	10.360	210
220	10.360	10.414	10.469	10.523	10.578	10.632	10.687	10.741	10.796	10.851	10.905	220
230	10.905	10.960	11.015	11.070	11.125	11.180	11.235	11.290	11.345	11.401	11.456	230
240	11.456	11.511	11.566	11.622	11.677	11.733	11.788	11.844	11.900	11.956	12.011	240
250	12.011	12.067	12.123	12.179	12.235	12.291	12.347	12.403	12.459	12.515	12.572	250
260	12.572	12.628	12.684	12.741	12.797	12.854	12.910	12.967	13.024	13.080	13.137	260
270	13.137	13.194	13.251	13.307	13.364	13.421	13.478	13.535	13.592	13.650	13.707	270
280	13.707	13.764	13.821	13.879	13.936	13.993	14.051	14.108	14.166	14.223	14.281	280
290	14.281	14.339	14.396	14.454	14.512	14.570	14.628	14.686	14.744	14.802	14.860	290
300	14.860	14.918	14.976	15.034	15.092	15.151	15.209	15.267	15.326	15.384	15.443	300
310	15.443	15.501	15.560	15.619	15.677	15.736	15.795	15.853	15.912	15.971	16.030	310
320	16.030	16.089	16.148	16.207	16.266	16.325	16.384	16.444	16.503	16.562	16.621	320
330	16.621	16.681	16.740	16.800	16.859	16.919	16.978	17.038	17.097	17.157	17.217	330
340	17.217	17.277	17.336	17.396	17.456	17.516	17.576	17.636	17.696	17.756	17.816	340
350	17.816	17.877	17.937	17.997	18.057	18.118	18.178	18.238	18.299	18.359	18.420	350
360	18.420	18.480	18.541	18.602	18.662	18.723	18.784	18.845	18.905	18.966	19.027	360
370	19.027	19.088	19.149	19.210	19.271	19.332	19.393	19.455	19.516	19.577	19.638	370
380	19.638	19.699	19.761	19.822	19.883	19.945	20.006	20.068	20.129	20.191	20.252	380
390	20.252	20.314	20.376	20.437	20.499	20.560	20.622	20.684	20.746	20.807	20.869	390

T/C Type T - Thermoelectric Voltage

As a Function of Temperature (°F) Reference Junctions at 32 °F
Reference Standard: NBS Monograph 125 and BS 4937 parts 1-7

Table 8.1.16 Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-460							-6.258	-6.257	-6.256	-6.255	-6.254	-460
-450	-6.254	-6.253	-6.252	-6.251	-6.250	-6.248	-6.247	-6.245	-6.243	-6.242	-6.240	-450
-440	-6.240	-6.238	-6.236	-6.234	-6.232	-6.230	-6.227	-6.225	-6.223	-6.220	-6.217	-440
-430	-6.217	-6.215	-6.212	-6.209	-6.206	-6.203	-6.200	-6.197	-6.194	-6.191	-6.187	-430
-420	-6.187	-6.184	-6.181	-6.177	-6.173	-6.170	-6.166	-6.162	-6.158	-6.154	-6.150	-420
-410	-6.150	-6.146	-6.142	-6.137	-6.133	-6.128	-6.124	-6.119	-6.115	-6.110	-6.105	-410
-400	-6.105	-6.100	-6.095	-6.090	-6.085	-6.080	-6.075	-6.069	-6.064	-6.059	-6.053	-400
-390	-6.053	-6.048	-6.042	-6.036	-6.030	-6.025	-6.019	-6.013	-6.007	-6.001	-5.995	-390
-380	-5.995	-5.988	-5.982	-5.976	-5.969	-5.963	-5.957	-5.950	-5.943	-5.937	-5.930	-380
-370	-5.930	-5.923	-5.916	-5.910	-5.903	-5.896	-5.889	-5.881	-5.874	-5.867	-5.860	-370
-360	-5.860	-5.853	-5.845	-5.838	-5.830	-5.823	-5.815	-5.808	-5.800	-5.792	-5.785	-360
-350	-5.785	-5.777	-5.769	-5.761	-5.753	-5.745	-5.737	-5.729	-5.721	-5.713	-5.705	-350
-340	-5.705	-5.697	-5.688	-5.680	-5.672	-5.663	-5.655	-5.646	-5.638	-5.629	-5.620	-340
-330	-5.620	-5.612	-5.603	-5.594	-5.585	-5.576	-5.568	-5.559	-5.550	-5.541	-5.532	-330
-320	-5.532	-5.522	-5.513	-5.504	-5.495	-5.486	-5.476	-5.457	-5.457	-5.448	-5.439	-320
-310	-5.439	-5.429	-5.419	-5.410	-5.400	-5.390	-5.381	-5.371	-5.361	-5.351	-5.341	-310
-300	-5.341	-5.331	-5.321	-5.311	-5.301	-5.291	-5.281	-5.271	-5.261	-5.250	-5.240	-300
-290	-5.240	-5.230	-5.219	-5.209	-5.198	-5.188	-5.177	-5.167	-5.156	-5.145	-5.135	-290
-280	-5.135	-5.124	-5.113	-5.102	-5.091	-5.080	-5.069	-5.058	-5.047	-5.036	-5.025	-280
-270	-5.025	-5.014	-5.003	-4.992	-4.980	-4.969	-4.958	-4.946	-4.935	-4.923	-4.912	-270
-260	-4.912	-4.900	-4.889	-4.877	-4.865	-4.853	-4.842	-4.830	-4.818	-4.806	-4.794	-260
-250	-4.794	-4.782	-4.770	-4.758	-4.746	-4.734	-4.722	-4.710	-4.698	-4.685	-4.673	-250
-240	-4.673	-4.661	-4.648	-4.636	-4.623	-4.611	-4.598	-4.586	-4.573	-4.560	-4.548	-240
-230	-4.548	-4.535	-4.522	-4.509	-4.497	-4.484	-4.471	-4.458	-4.445	-4.432	-4.419	-230
-220	-4.419	-4.406	-4.392	-4.379	-4.366	-4.353	-4.339	-4.326	-4.313	-4.299	-4.286	-220
-210	-4.286	-4.272	-4.259	-4.245	-4.232	-4.218	-4.204	-4.191	-4.177	-4.163	-4.149	-210
-200	-4.149	-4.135	-4.121	-4.107	-4.093	-4.079	-4.065	-4.051	-4.037	-4.023	-4.009	-200
-190	-4.009	-3.994	-3.980	-3.966	-3.951	-3.937	-3.923	-3.908	-3.894	-3.879	-3.864	-190
-180	-3.864	-3.850	-3.835	-3.820	-3.806	-3.791	-3.776	-3.761	-3.746	-3.732	-3.717	-180
-170	-3.717	-3.702	-3.687	-3.671	-3.656	-3.641	-3.626	-3.611	-3.596	-3.580	-3.565	-170
-160	-3.565	-3.550	-3.534	-3.519	-3.503	-3.488	-3.472	-3.457	-3.441	-3.425	-3.410	-160
-150	-3.410	-3.394	-3.378	-3.362	-3.647	-3.661	-3.615	-3.299	-3.283	-3.267	-3.251	-150
-140	-3.251	-3.235	-3.219	-3.203	-3.186	-3.170	-3.154	-3.138	-3.121	-3.105	-3.089	-140
-130	-3.089	-3.072	-3.056	-3.039	-3.023	-3.006	-2.989	-2.973	-2.956	-2.939	-2.923	-130
-120	-2.923	-2.906	-2.889	-2.872	-2.855	-2.838	-2.822	-2.805	-2.788	-2.771	-2.753	-120
-110	-2.753	-2.736	-2.719	-2.702	-2.685	-2.667	-2.650	-2.633	-2.616	-2.598	-2.581	-110
-100	-2.581	-2.563	-2.546	-2.528	-2.511	-2.493	-2.475	-2.458	-2.440	-2.422	-2.405	-100
-90	-2.405	-2.387	-2.369	-2.351	-2.333	-2.315	-2.297	-2.279	-2.261	-2.243	-2.225	-90
-80	-2.225	-2.207	-2.189	-2.171	-2.152	-2.134	-2.116	-2.098	-2.079	-2.061	-2.042	-80
-70	-2.042	-2.024	-2.005	-1.987	-1.968	-1.950	-1.931	-1.912	-1.894	-1.875	-1.856	-70
-60	-1.856	-1.838	-1.819	-1.800	-1.781	-1.762	-1.743	-1.724	-1.705	-1.686	-1.667	-60
-50	-1.667	-1.648	-1.629	-1.610	-1.591	-1.571	-1.552	-1.533	-1.513	-1.494	-1.475	-50
-40	-1.475	-1.455	-1.436	-1.416	-1.397	-1.377	-1.358	-1.338	-1.319	-1.299	-1.279	-40
-30	-1.279	-1.260	-1.240	-1.220	-1.200	-1.180	-1.160	-1.141	-1.121	-1.101	-1.081	-30
-20	-1.081	-1.061	-1.041	-1.021	-1.000	-0.980	-0.960	-0.940	-0.920	-0.899	-0.879	-20
-10	-0.879	-0.859	-0.838	-0.818	-0.798	-0.777	-0.757	-0.736	-0.716	-0.695	-0.674	-10
0	-0.674	-0.654	-0.633	-0.613	-0.592	-0.571	-0.550	-0.529	-0.509	-0.488	-0.467	0

Table 8.1.16 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
10	-0.467	-0.446	-0.425	-0.404	-0.383	-0.362	-0.341	-0.320	-0.299	-0.277	-0.256	10
20	-0.256	-0.235	-0.214	-0.193	-0.171	-0.150	-0.129	-0.107	-0.086	-0.064	-0.043	20
30	-0.043	-0.022	0.000	0.022	0.043	0.065	0.086	0.108	0.130	0.151	0.173	30
40	0.173	0.195	0.216	0.238	0.260	0.282	0.303	0.325	0.347	0.369	0.391	40
50	0.391	0.413	0.435	0.457	0.479	0.501	0.523	0.545	0.567	0.589	0.611	50
60	0.611	0.634	0.656	0.678	0.700	0.722	0.745	0.767	0.789	0.812	0.834	60
70	0.834	0.857	0.879	0.902	0.924	0.947	0.969	0.992	1.014	1.037	1.060	70
80	1.060	1.082	1.105	1.128	1.151	1.173	1.196	1.219	1.242	1.265	1.288	80
90	1.288	1.311	1.334	1.357	1.380	1.403	1.426	1.449	1.472	1.495	1.518	90
100	1.518	1.542	1.565	1.588	1.611	1.635	1.658	1.681	1.705	1.728	1.752	100
110	1.752	1.775	1.799	1.822	1.846	1.869	1.893	1.917	1.940	1.964	1.988	110
120	1.988	2.011	2.035	2.059	2.083	2.107	2.131	2.154	2.178	2.202	2.226	120
130	2.226	2.250	2.274	2.298	2.322	2.347	2.371	2.395	2.419	2.443	2.467	130
140	2.467	2.492	2.516	2.540	2.565	2.589	2.613	2.638	2.662	2.687	2.711	140
150	2.711	2.736	2.760	2.785	2.809	2.834	2.859	2.883	2.908	2.933	2.958	150
160	2.958	2.982	3.007	3.032	3.057	3.082	3.107	3.131	3.156	3.181	3.206	160
170	3.206	3.231	3.256	3.281	3.307	3.332	3.357	3.382	3.407	3.432	3.458	170
180	3.458	3.483	3.508	3.533	3.559	3.584	3.609	3.635	3.660	3.686	3.711	180
190	3.711	3.737	3.762	3.788	3.813	3.839	3.864	3.890	3.916	3.941	3.967	190
200	3.967	3.993	4.019	4.044	4.070	4.096	4.122	4.148	4.174	4.199	4.225	200
210	4.225	4.251	4.277	4.303	4.329	4.355	4.381	4.408	4.434	4.460	4.486	210
220	4.486	4.512	4.538	4.565	4.591	4.617	4.643	4.670	4.696	4.722	4.749	220
230	4.749	4.775	4.801	4.828	4.854	4.881	4.907	4.934	4.960	4.987	5.014	230
240	5.014	5.040	5.067	5.093	5.120	5.147	5.174	5.200	5.227	5.254	5.281	240
250	5.281	5.307	5.334	5.361	5.388	5.415	5.442	5.469	5.496	5.523	5.550	250
260	5.550	5.577	5.604	5.631	5.658	5.685	5.712	5.739	5.767	5.794	5.821	260
270	5.821	5.848	5.875	5.903	5.930	5.957	5.985	6.012	6.039	6.067	6.094	270
280	6.094	6.122	6.149	6.177	6.204	6.232	6.259	6.287	6.314	6.342	6.369	280
290	6.369	6.397	6.425	6.452	6.480	6.508	6.536	6.563	6.591	6.619	6.647	290
300	6.647	6.675	6.702	6.730	6.758	6.786	6.814	6.842	6.870	6.898	6.926	300
310	6.926	6.954	6.982	7.010	7.038	7.066	7.094	7.122	7.151	7.179	7.207	310
320	7.207	7.235	7.263	7.292	7.320	7.348	7.377	7.405	7.433	7.462	7.490	320
330	7.490	7.518	7.547	7.575	7.604	7.632	7.661	7.689	7.718	7.746	7.775	330
340	7.775	7.804	7.832	7.861	7.889	7.918	7.947	7.975	8.004	8.033	8.062	340
350	8.062	8.090	8.119	8.148	8.177	8.206	8.235	8.264	8.292	8.321	8.350	350
360	8.350	8.379	8.408	8.437	8.466	8.495	8.524	8.553	8.583	8.612	8.641	360
370	8.641	8.670	8.699	8.728	8.757	8.787	8.816	8.845	8.874	8.904	8.933	370
380	8.933	8.962	8.992	9.021	9.050	9.080	9.109	9.139	9.168	9.198	9.227	380
390	9.227	9.257	9.286	9.316	9.345	9.375	9.404	9.434	9.464	9.493	9.523	390
400	9.523	9.553	9.582	9.612	9.642	9.671	9.701	9.731	9.761	9.791	9.820	400
410	9.820	9.850	9.880	9.910	9.940	9.970	10.000	10.030	10.060	10.090	10.120	410
420	10.120	10.150	10.180	10.210	10.240	10.270	10.300	10.330	10.360	10.390	10.420	420
430	10.420	10.451	10.481	10.511	10.541	10.572	10.602	10.632	10.662	10.693	10.723	430
440	10.723	10.753	10.784	10.814	10.845	10.875	10.905	10.936	10.966	10.997	11.027	440
450	11.027	11.058	11.088	11.119	11.149	11.180	11.211	11.241	11.272	11.302	11.333	450
460	11.333	11.364	11.394	11.425	11.456	11.487	11.517	11.548	11.579	11.610	11.640	460
470	11.640	11.671	11.702	11.733	11.764	11.795	11.826	11.856	11.887	11.918	11.949	470
480	11.949	11.980	12.011	12.042	12.073	12.104	12.135	12.166	12.198	12.229	12.260	480
490	12.260	12.291	12.322	12.353	12.384	12.416	12.447	12.478	12.509	12.540	12.572	490
500	12.572	12.603	12.634	12.666	12.697	12.728	12.760	12.791	12.822	12.854	12.885	500
510	12.885	12.917	12.948	12.979	13.011	13.042	13.074	13.105	13.137	13.168	13.200	510
520	13.200	13.232	13.263	13.295	13.326	13.358	13.390	13.421	13.453	13.485	13.516	520
530	13.516	13.548	13.580	13.611	13.643	13.675	13.707	13.739	13.770	13.802	13.834	530

Table 8.1.16 cont. Thermoelectric Voltage in Absolute Millivolts

°F	0	1	2	3	4	5	6	7	8	9	10	°F
540	13.834	13.866	13.898	13.930	13.961	13.993	14.025	14.057	14.089	14.121	14.153	540
550	14.153	14.185	14.217	14.249	14.281	14.313	14.345	14.377	14.409	14.441	14.474	550
560	14.474	14.506	14.538	14.570	14.602	14.634	14.666	14.699	14.731	14.763	14.795	560
570	14.795	14.828	14.860	14.892	14.924	14.957	14.989	15.021	15.054	15.086	15.118	570
580	15.118	15.151	15.183	15.216	15.248	15.280	15.313	15.345	15.378	15.410	15.443	580
590	15.443	15.475	15.508	15.540	15.573	15.605	15.638	15.871	15.703	15.736	15.769	590
600	15.769	15.801	15.834	15.866	15.899	15.932	15.965	15.997	16.030	16.063	16.096	600
610	16.096	16.128	16.161	16.194	16.227	16.259	16.292	16.325	16.358	16.391	16.424	610
620	16.424	16.457	16.490	16.523	16.555	16.588	16.621	16.654	16.687	16.720	16.753	620
630	16.753	16.786	16.819	16.852	16.886	16.919	16.952	16.985	17.018	17.051	17.084	630
640	17.084	17.117	17.150	17.184	17.217	17.250	17.283	17.316	17.350	17.383	17.416	640
650	17.416	17.450	17.483	17.516	17.549	17.583	17.616	17.649	17.683	17.716	17.750	650
660	17.750	17.783	17.816	17.850	17.883	17.917	17.950	17.984	18.017	18.051	18.084	660
670	18.084	18.118	18.151	18.185	18.218	18.252	18.285	18.319	18.353	18.386	18.420	670
680	18.420	18.454	18.487	18.521	18.555	18.588	18.622	18.656	18.689	18.723	18.757	680
690	18.757	18.791	18.824	18.858	18.892	18.926	18.960	18.993	19.027	19.061	19.095	690
700	19.095	19.129	19.163	19.197	19.230	19.264	19.298	19.332	19.366	19.400	19.434	700
710	19.434	19.468	19.502	19.536	19.570	19.604	19.638	19.672	19.706	19.740	19.774	710
720	19.774	19.808	19.843	19.877	19.911	19.945	19.979	20.013	20.047	20.081	20.116	720
730	20.116	20.150	20.184	20.218	20.252	20.287	20.321	20.355	20.389	20.423	20.458	730
740	20.458	20.492	20.526	20.560	20.595	20.629	20.663	20.698	20.732	20.766	20.801	740
750	20.801	20.835	20.869									750

8.1 – Tables
Wire

TABLE PAGE

Table 8.1.17 Thermocouple Wire Identification

ANSI Code	Alloy Combination		Color Coding	DIN 4
	+Lead	-Lead		
B	Platinum-30% Rhodium Pt-30% Rh	Platinum-6% Rhodium Pt-6% Rh	None Established	
E	Chromel Nickel-Chromium Ni-Cr	Constantan Copper-Nickel Cu-Ni	+Purple -Red	
J	Iron Fe	Constantan Copper-Nickel Cu-Ni	+White -Red	+Red -Blue
K	Chromel Nickel-Chromium Ni-Cr	Alumel Nickel-Alumel Ni-Al	+Yellow -Red	+Red -Green
N(1)	Omega-P™ Nicrosil Ni-Cr-Si	Omega-N™ NISIL Ni-Si-Mg	+Orange -Red	
R	Platinum-13% Rhodium Pt-13% Rh	Platinum Pt	None Established	
S	Platinum-10% Rhodium Pt-10% Rh	Platinum Pt	None Established	+Red(2) -White(2)
T	Copper Cu	Constantan Copper-Nickel Cu-Ni	+Blue -Red	+Red -Brown

(1) Not Official Symbol or Standard
(2) Extension Grade

Table 8.1.18 Resistance vs. Wire Diameter

		Resistance in Ohms per Double Foot at 68 °F					
AWG No.	Diameter (Inches)	Type K Chromel/ Alumel	Type J Iron/ Constantan	Type T Copper/ Constantan	Type E Chromel/ Constantan	Type S Pt/Pt10% Rh	Type R Pt/Pt13% Rh
6	0.162	0.023	0.014	0.012	0.027	0.007	0.007
8	0.128	0.037	0.022	0.019	0.044	0.011	0.011
10	0.102	0.058	0.034	0.029	0.069	0.018	0.018
12	0.081	0.091	0.054	0.046	0.109	0.028	0.029
14	0.064	0.146	0.087	0.074	0.175	0.045	0.047
16	0.051	0.230	0.137	0.117	0.276	0.071	0.073
18	0.040	0.374	0.222	0.190	0.448	0.116	0.119
20	0.032	0.586	0.357	0.298	0.707	0.185	0.190
24	0.0201	1.490	0.878	0.7526	1.78	0.464	0.478
26	0.0159	2.381	1.405	1.204	2.836	0.740	0.760
30	0.0100	5.984	3.551	3.043	7.169	1.85	1.91
32	0.0080	9.524	5.599	4.758	11.31	1.96	3.04
34	0.0063	15.17	8.946	7.66	18.09	4.66	4.82
36	0.0050	24.08	14.20	12.17	28.76	7.40	7.64
38	0.0039	38.20	23.35	19.99	45.41	11.6	11.95
40	0.00315	60.88	37.01	31.64	73.57	18.6	19.3
44	0.0020	149.6	88.78	76.09	179.2	74.0	76.5
50	0.0010	598.4	355.1	304.3	716.9	185	191
56	0.00049	2408	1420	1217	2816	740	764

Table 8.1.19 Wire Table, Standard Annealed Copper

American Wire Gage English Units			
Gage No. A.W.G.	Diameter in Mils at 20°C	Ohms per 1000 ft(1) at 20°C (68°F)	Feet per Ohm(2) at 20°C (68°F)
0000	460.0	0.04901	20,400.0
000	409.6	0.06180	16,180.0
00	364.8	0.07793	12,830.0
0	324.9	0.09827	10,180.0
1	289.3	0.1239	8,070.0
2	257.6	0.1563	6,400.0
3	229.4	0.1970	5,075.0
4	204.3	0.2485	4,025.0
5	181.9	0.3133	3,192.0
6	162.0	0.3951	2,531.0
7	144.3	0.4982	2,007.0
8	128.5	0.6282	1,592.0
9	114.4	0.7921	1,262.0
10	101.9	0.9989	1,001.0
11	90.74	1.260	794.0
12	80.81	1.588	629.6
13	71.96	2.003	499.3
14	64.08	2.525	396.0
15	57.07	3.184	314.0
16	50.82	4.016	249.0
17	45.26	5.064	197.5
18	40.30	6.385	156.6
19	35.89	8.051	124.2
20	31.96	10.15	98.50
21	28.46	12.80	78.11
22	25.35	16.14	61.95
23	22.57	20.36	49.13
24	20.10	25.67	38.96
25	17.90	32.37	30.90
26	15.94	40.81	24.50
27	14.20	51.47	19.43
28	12.64	64.90	15.41
29	11.26	81.83	12.22
30	10.03	103.2	9.691
31	8.928	130.1	7.685
32	7.950	164.1	6.095
33	7.080	206.9	4.833
34	6.305	260.9	3.833
35	5.615	329.0	3.040
36	5.000	414.8	2.411
37	4.453	523.1	1.912
38	3.965	659.6	1.516
39	3.531	831.8	1.202
40	3.145	1049.0	0.9534

(1) Resistance at the stated temperatures of a wire whose length is 1000 ft at 20°C.
(2) Length at 20°C of a wire whose resistance is 1 ohm at the stated temperatures.

8.1 – Tables

RTDs

Platinum 100, Alpha = 0.00385

Resistance as a Function of Temperature (°C)
Reference Standard: IEC 751

Table 8.1.20 Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-200	18.49	18.93	19.36	19.79	20.22	20.65	21.08	21.51	21.94	22.37	22.80	-200
-190	22.80	23.23	23.66	24.09	24.53	24.94	25.37	25.80	26.23	26.65	27.08	-190
-180	27.08	27.50	27.93	28.35	28.78	28.20	28.63	30.05	30.47	30.90	31.32	-180
-170	31.32	31.74	32.16	32.59	33.01	33.43	33.85	34.27	34.69	35.11	35.53	-170
-160	35.53	35.95	36.37	36.79	37.21	37.63	38.04	38.46	38.88	39.30	39.71	-160
-150	39.71	40.13	40.55	40.96	41.38	41.79	42.21	42.63	43.04	43.45	43.87	-150
-140	43.87	44.28	44.70	45.11	45.52	45.94	46.35	46.76	47.18	47.59	48.00	-140
-130	48.00	48.41	48.82	49.23	49.64	50.06	50.47	50.88	51.29	51.70	52.11	-130
-120	52.11	52.52	52.92	53.33	53.74	54.15	54.56	54.97	55.38	55.78	56.19	-120
-110	56.19	56.60	57.00	57.41	57.82	58.22	58.63	59.04	59.44	59.85	60.25	-110
-100	30.25	60.66	61.06	61.47	61.87	62.28	62.68	63.09	63.49	63.90	64.30	-100
-90	64.30	64.70	65.11	65.51	65.91	66.31	66.72	67.12	67.52	67.91	68.33	-90
-80	68.33	68.73	69.13	69.53	69.93	70.33	70.73	74.13	71.53	71.93	72.33	-80
-70	72.33	72.73	73.13	73.53	73.93	74.33	74.73	75.13	75.53	75.93	76.33	-70
-60	76.33	76.73	77.13	77.52	77.92	78.32	78.72	79.11	79.51	79.91	80.31	-60
-50	80.31	80.70	81.10	81.50	81.89	82.29	82.69	83.08	83.48	83.88	84.27	-50
-40	84.27	84.67	85.06	85.46	85.85	86.25	86.64	87.04	87.43	87.83	88.22	-40
-30	88.22	88.62	89.01	89.40	89.80	90.19	90.59	90.98	91.37	91.77	92.16	-30
-20	92.16	92.55	92.95	93.34	93.73	94.12	94.52	94.91	95.30	95.69	96.09	-20
-10	96.09	96.48	96.87	97.26	97.65	98.04	98.44	98.83	99.22	99.61	100.00	-10
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51	103.90	0
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40	107.79	10
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.28	111.67	20
30	111.67	112.06	112.45	112.83	113.22	113.61	113.99	114.38	114.77	115.15	115.54	30
40	115.54	115.93	116.31	116.70	117.08	117.47	117.85	118.24	118.62	119.01	119.40	40
50	119.40	119.78	120.16	120.55	120.93	121.32	121.70	122.09	122.47	122.86	123.24	50
60	123.24	123.62	124.01	124.39	124.77	125.16	125.54	125.92	126.31	126.69	127.07	60
70	127.07	127.45	127.84	128.22	128.60	128.98	129.37	129.75	130.13	130.51	130.89	70

Table 8.1.20 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
80	130.89	131.27	131.66	132.04	132.42	132.80	133.18	133.56	133.94	134.32	134.70	80
90	134.70	135.08	135.46	135.84	136.22	136.60	136.98	137.36	137.74	138.12	138.50	90
100	138.50	138.88	139.26	139.64	140.02	140.39	140.77	141.15	141.53	141.91	142.29	100
110	142.29	142.66	143.04	143.42	143.80	144.17	144.55	144.93	145.31	145.68	146.06	110
120	146.06	146.44	146.81	147.19	147.57	147.94	148.32	148.70	149.07	149.45	149.82	120
130	149.82	150.20	150.57	150.95	151.33	151.70	152.08	152.45	152.83	153.20	153.58	130
140	153.58	153.95	154.32	154.70	155.07	155.45	155.82	156.19	156.57	156.94	157.31	140
150	157.31	157.69	158.06	158.43	158.81	159.18	159.55	159.93	160.30	160.67	161.04	150
160	161.04	161.42	161.79	162.16	162.53	162.90	163.27	163.65	164.02	164.39	164.76	160
170	164.76	165.13	165.50	165.87	166.24	166.61	166.98	167.35	167.72	168.09	168.46	170
180	168.46	168.83	169.20	169.57	169.94	170.31	170.68	171.05	171.42	171.79	172.16	180
190	172.16	172.53	172.90	173.26	173.63	174.00	174.37	174.74	175.10	175.47	175.84	190
200	175.84	176.21	176.57	176.94	177.31	177.68	178.04	178.41	178.78	179.14	179.51	200
210	179.51	179.88	180.24	180.61	180.97	181.34	181.71	182.07	182.44	182.80	183.17	210
220	183.17	183.53	183.90	184.26	184.63	184.99	185.36	185.72	186.09	186.45	186.82	220
230	186.82	187.18	187.54	187.91	188.27	188.63	189.00	189.36	189.72	190.09	190.45	230
240	190.45	190.81	191.18	191.54	191.90	192.26	192.63	192.99	193.35	193.71	194.07	240
250	194.07	194.44	194.80	195.16	195.52	195.88	196.24	196.60	196.96	197.33	197.69	250
260	197.69	198.05	198.41	198.77	199.13	199.49	199.85	200.21	200.57	200.93	201.29	260
270	201.29	201.65	202.01	202.36	202.72	203.08	203.44	203.80	204.16	204.52	204.88	270
280	204.88	205.23	205.59	205.95	206.31	206.67	207.02	207.38	207.74	208.10	208.45	280
290	208.45	208.81	209.17	209.52	209.88	210.24	210.59	210.95	211.31	211.66	212.02	290
300	212.02	212.37	212.73	213.09	213.44	213.80	214.15	214.51	214.86	215.22	215.57	300
310	215.57	215.93	216.28	216.64	216.99	217.35	217.70	218.05	218.41	218.76	219.12	310
320	219.12	219.47	219.82	220.18	220.53	220.88	221.24	221.59	221.94	222.29	222.65	320
330	222.65	223.00	223.35	223.70	224.06	224.41	224.76	225.11	225.46	225.81	226.17	330
340	226.17	226.52	226.87	227.22	227.57	227.92	228.27	228.62	228.97	229.32	229.67	340
350	229.67	230.02	230.37	230.72	231.07	231.42	231.77	232.12	232.47	232.82	233.17	350
360	233.17	233.52	233.87	234.22	234.56	234.91	235.26	235.61	235.96	236.31	236.65	360
370	236.65	237.00	237.35	237.70	238.04	238.39	238.74	239.09	239.43	239.78	240.13	370
380	240.13	240.47	240.82	241.17	241.51	241.86	242.20	242.55	242.90	243.24	243.59	380
390	243.59	243.93	244.28	244.62	244.97	245.31	245.66	246.00	246.35	246.69	247.04	390
400	247.04	247.38	247.73	248.07	248.41	248.76	249.10	249.45	249.79	250.13	250.48	400
410	250.48	250.82	251.16	251.50	251.85	252.19	252.53	252.88	253.22	253.56	253.90	410
420	253.90	254.24	254.59	254.93	255.27	255.61	255.95	256.29	256.63	256.98	257.32	420
430	257.32	257.66	258.00	258.34	258.68	259.02	259.36	259.70	260.04	260.38	260.72	430
440	260.72	261.06	261.40	261.74	262.08	262.42	262.76	263.10	263.43	263.77	264.11	440
450	264.11	264.45	264.79	265.13	265.47	265.80	266.14	266.48	266.82	267.15	267.49	450
460	267.49	267.83	268.17	268.50	268.84	269.18	269.51	269.85	270.19	270.52	270.86	460
470	270.86	271.20	271.53	271.87	272.20	272.54	272.88	273.21	273.55	273.88	274.22	470
480	274.22	274.55	274.89	275.22	275.56	275.89	276.23	276.56	276.89	277.23	277.56	480
490	277.56	277.90	278.23	278.56	278.90	279.23	279.56	279.90	280.23	280.56	280.90	490
500	280.90	281.23	281.56	281.89	282.23	282.56	282.89	283.22	283.55	283.89	284.22	500
510	284.22	284.55	284.88	285.21	285.54	285.87	286.21	286.54	286.87	287.20	287.53	510
520	287.53	287.86	288.19	288.52	288.85	289.18	289.51	289.84	290.17	290.50	290.83	520
530	290.83	291.16	291.49	291.81	292.14	292.47	292.80	293.13	293.46	293.79	294.11	530
540	294.11	294.44	294.77	295.10	295.43	295.75	296.08	296.41	296.74	297.06	297.39	540
550	297.39	297.72	298.04	298.37	298.70	299.02	299.35	299.68	300.00	300.33	300.65	550
560	300.65	300.98	301.31	301.63	301.96	302.28	302.61	302.93	303.26	303.58	303.91	560
570	303.91	304.23	304.56	304.88	305.20	305.53	305.85	306.18	306.50	306.82	307.15	570
580	307.15	307.47	307.79	308.12	308.44	308.76	309.09	309.41	309.73	310.05	310.38	580
590	310.38	310.70	311.02	311.34	311.66	311.99	312.31	312.63	312.95	313.27	313.59	590
600	313.59	313.92	314.24	314.56	314.88	315.20	315.52	315.84	316.16	316.48	316.80	600

Table 8.1.20 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
610	316.80	317.12	317.44	317.76	318.08	318.40	318.72	319.04	319.36	319.68	319.99	610
620	319.99	320.31	320.63	320.95	321.27	321.59	321.91	322.22	322.54	322.86	323.18	620
630	323.18	323.49	323.81	324.13	324.45	324.76	325.08	325.40	325.72	326.03	326.35	630
640	326.35	326.66	326.98	327.30	327.61	327.93	328.25	328.56	328.88	329.19	329.51	640
650	329.51	329.82	330.14	330.45	330.77	331.08	331.40	331.71	332.03	332.34	332.66	650
660	332.66	332.97	333.28	333.60	333.91	334.23	334.54	334.85	335.17	335.48	335.79	660
670	335.79	336.11	336.42	336.73	337.04	337.36	337.67	337.98	338.29	338.61	338.92	670
680	338.92	339.23	339.54	339.85	340.16	340.47	340.79	341.10	341.41	341.72	342.03	680
690	342.03	342.34	342.65	342.96	343.27	343.58	343.89	344.20	344.51	344.82	345.13	690
700	345.13	345.44	345.75	346.06	346.37	346.68	346.99	347.30	347.60	347.91	348.22	700
710	348.22	348.53	348.84	349.15	349.45	349.76	350.07	350.38	350.69	350.99	351.30	710
720	351.30	351.61	351.91	352.22	352.53	352.83	353.14	353.45	353.75	354.06	354.37	720
730	354.37	354.67	354.98	355.28	355.59	355.90	356.20	356.51	356.81	357.12	357.42	730
740	357.42	357.73	358.03	358.34	358.64	358.94	359.25	359.55	359.86	360.16	360.47	740
750	360.47	360.77	361.07	361.38	361.68	361.98	362.29	362.59	362.89	363.19	363.50	750
760	363.50	363.80	364.10	364.40	364.71	365.01	365.31	365.61	365.91	366.22	366.52	760
770	366.52	366.82	367.12	367.42	367.72	368.02	368.32	368.62	368.93	369.23	369.53	770
780	369.53	369.83	370.13	370.43	370.73	371.03	371.33	371.63	371.92	372.22	372.52	780
790	372.52	372.82	373.12	373.42	373.72	374.02	374.32	374.61	374.92	375.21	375.51	790
800	375.51	375.81	376.10	376.40	376.70	377.00	377.29	377.59	377.89	378.19	378.48	800
810	378.48	378.78	379.08	379.37	379.67	379.97	380.26	380.56	380.85	381.15	381.45	810
820	381.45	381.74	382.04	382.33	382.63	382.92	383.22	383.51	383.81	384.10	384.40	820
830	384.40	384.69	384.98	385.28	385.57	385.87	386.16	386.45	386.75	387.04	387.33	830
840	387.33	387.63	387.92	388.21	388.51	388.80	389.09	389.39	389.68	389.97	390.26	840

Platinum 100, Alpha = 0.00385

Resistance as a Function of Temperature (°F)
Reference Standard: IEC 751

Table 8.1.21 Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-330	18.01	18.25	18.49	18.73	18.97	19.21	19.45	19.69	19.93	20.17	20.41	-330
-320	20.41	20.65	20.89	21.13	21.37	21.61	21.85	22.09	22.33	22.56	22.80	-320
-310	22.80	23.04	23.28	23.52	23.76	23.99	24.23	24.47	24.71	24.94	25.18	-310
-300	25.18	25.43	25.66	25.89	26.13	26.37	26.60	26.84	27.08	27.31	27.55	-300
-290	27.55	27.79	28.02	28.26	28.50	28.73	28.97	29.20	29.44	29.67	29.91	-290
-280	29.91	30.14	30.38	30.62	30.85	31.09	31.32	31.55	31.79	32.02	32.26	-280
-270	32.26	32.49	32.73	32.96	33.20	33.43	33.66	33.90	34.13	34.36	34.60	-270
-260	34.60	34.83	35.06	35.30	35.53	35.76	36.00	36.23	36.46	36.70	36.93	-260
-250	36.93	37.16	37.39	37.63	37.86	38.09	38.32	38.55	38.79	39.02	39.25	-250
-240	39.25	39.48	39.71	39.95	40.18	40.41	40.64	40.87	41.10	41.33	41.56	-240
-230	41.56	41.79	42.03	42.26	42.49	42.72	42.95	43.18	43.41	43.64	43.87	-230
-220	43.87	44.10	44.33	44.56	44.79	45.02	45.25	45.48	45.71	45.94	46.17	-220
-210	46.17	46.40	46.63	46.85	47.08	47.31	47.54	47.77	48.00	48.23	48.46	-210
-200	48.46	48.69	48.91	49.14	49.37	49.60	49.83	50.06	50.28	50.51	50.74	-200
-190	50.74	50.97	51.20	51.42	51.65	51.88	52.11	52.33	52.56	52.79	53.02	-190
-180	53.02	53.24	53.47	53.70	53.92	54.15	54.38	54.60	54.83	55.06	55.28	-180
-170	55.28	55.51	55.74	55.96	56.19	56.42	56.64	56.87	57.10	57.32	57.55	-170
-160	57.55	57.77	58.00	58.22	58.45	58.68	58.90	59.13	59.35	59.58	59.80	-160
-150	59.80	60.03	60.25	60.48	60.70	60.93	61.15	61.38	61.60	61.83	62.05	-150

Table 8.1.21 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-140	62.05	62.28	62.50	62.73	62.95	6318	63.40	63.63	63.85	64.07	64.30	-140
-130	64.30	64.52	64.75	64.97	65.19	65.42	65.64	65.87	66.09	66.31	66.54	-130
-120	66.54	66.76	66.98	67.21	67.43	67.66	67.88	68.10	68.33	68.55	68.77	-120
-110	68.77	68.99	69.22	69.44	69.66	69.89	70.11	70.33	70.55	70.78	71.00	-110
-100	71.00	71.22	71.45	71.67	71.89	72.11	72.33	72.56	72.78	73.00	73.22	-100
-90	73.22	73.45	73.67	73.89	74.11	74.33	74.56	74.78	75.00	75.22	75.44	-90
-80	75.44	75.66	75.89	76.11	76.33	76.55	76.77	76.99	77.21	77.43	77.66	-80
-70	77.66	77.88	78.10	78.32	78.54	78.76	78.98	79.20	79.42	79.64	79.87	-70
-60	79.87	80.09	80.31	80.53	80.75	80.97	81.19	81.41	81.63	81.85	82.07	-60
-50	82.07	82.29	82.51	82.73	82.95	83.17	83.39	83.61	83.83	84.05	84.27	-50
-40	84.27	84.49	84.71	84.93	85.15	85.37	85.59	85.81	86.03	86.25	86.47	-40
-30	86.47	86.69	86.91	87.13	87.35	87.56	87.78	88.00	88.22	88.44	88.66	-30
-20	88.66	88.88	89.10	89.32	89.54	89.76	89.97	90.19	90.41	90.63	90.85	-20
-10	90.85	91.07	91.29	91.50	91.72	91.94	92.16	92.38	92.60	92.82	93.03	-10
0	93.03	93.25	93.47	93.69	93.91	94.12	94.34	94.56	94.78	95.00	95.21	0
10	95.21	95.43	95.65	95.87	96.09	96.30	96.52	96.74	96.96	97.17	97.39	10
20	97.39	97.61	97.83	98.04	98.26	98.48	98.70	98.91	99.13	99.35	99.57	20
30	99.57	99.78	100.00	100.22	100.43	100.65	100.87	101.09	101.30	101.52	101.74	30
40	101.74	101.95	102.17	102.39	102.60	102.82	103.04	103.25	103.47	103.69	103.90	40
50	103.90	104.12	104.34	104.55	104.77	104.98	105.20	105.42	105.63	105.85	106.07	50
60	106.07	106.28	106.50	106.71	106.93	107.15	107.36	107.58	107.79	108.01	108.22	60
70	108.22	108.44	108.66	108.87	109.09	109.30	109.52	109.73	109.95	110.16	110.38	70
80	110.38	110.60	110.81	111.03	111.24	111.46	111.67	111.89	112.10	112.32	112.53	80
90	112.53	112.75	112.96	113.18	113.39	113.61	113.82	114.04	114.25	114.47	114.68	90
100	114.68	114.90	115.11	115.32	115.54	115.75	115.97	116.18	116.40	116.61	116.83	100
110	116.83	117.04	117.25	117.47	117.68	117.90	118.11	118.33	118.54	118.75	118.97	110
120	118.97	119.18	119.40	119.61	119.82	120.04	120.25	120.46	120.68	120.89	121.11	120
130	121.11	121.32	121.53	121.75	121.96	122.17	122.39	122.60	122.81	123.03	123.24	130
140	123.24	123.45	123.67	123.88	124.09	124.31	124.52	124.73	124.94	125.16	125.37	140
150	125.37	125.58	125.80	126.01	126.22	126.43	126.65	126.86	127.07	127.28	127.50	150
160	127.50	127.71	127.92	128.13	128.35	128.56	128.77	128.98	129.20	129.41	129.62	160
170	129.62	129.83	130.04	130.26	130.47	130.68	130.89	131.10	131.32	131.53	131.74	170
180	131.74	131.95	132.16	132.38	132.59	132.80	133.01	133.22	133.43	133.65	133.86	180
190	133.86	134.07	134.28	134.49	134.70	134.91	135.12	135.34	135.55	135.76	135.97	190
200	135.97	136.18	136.39	136.60	136.81	137.02	137.24	137.45	137.66	137.87	138.08	200
210	138.08	138.29	138.50	138.71	138.92	139.13	139.34	139.55	139.76	139.97	140.18	210
220	140.18	140.39	140.60	140.82	141.03	141.24	141.45	141.66	141.87	142.08	142.29	220
230	142.29	142.50	142.71	142.92	143.13	143.34	143.55	143.76	143.97	144.17	144.38	230
240	144.38	144.59	144.80	145.01	145.22	145.43	145.64	145.85	146.06	146.27	146.48	240
250	146.48	146.69	146.90	147.11	147.32	147.53	147.73	147.94	148.15	148.36	148.57	250
260	148.57	148.78	148.99	149.20	149.41	149.61	149.82	150.03	150.24	150.45	150.66	260
270	150.66	150.87	151.08	151.28	151.49	151.70	151.91	152.12	152.33	152.53	152.74	270
280	152.74	152.95	153.16	153.37	153.58	153.78	153.99	154.20	154.41	154.62	154.82	280
290	154.82	155.03	155.24	155.45	155.65	155.86	156.07	156.28	156.48	156.69	156.90	290
300	156.90	157.11	157.31	157.52	157.73	157.94	158.14	158.35	158.56	158.77	158.97	300
310	158.97	159.18	159.39	159.59	159.80	160.01	160.22	160.42	160.63	160.84	161.04	310
320	161.04	161.25	161.46	161.66	161.87	162.08	162.28	162.49	162.70	162.90	163.11	320
330	163.11	163.32	163.52	163.73	163.93	164.14	164.35	164.55	164.76	164.97	165.17	330
340	165.17	165.38	165.58	165.79	166.00	166.20	166.41	166.61	166.82	167.03	167.23	340
350	167.23	167.44	167.64	167.85	168.05	168.26	168.46	168.67	168.88	169.08	169.29	350
360	169.29	169.49	169.70	169.90	170.11	170.31	170.52	170.72	170.93	171.13	171.34	360
370	171.34	171.54	171.75	171.95	172.16	172.36	172.57	172.77	172.98	173.18	173.39	370
380	173.39	173.59	173.80	174.00	174.20	174.41	174.61	174.82	175.02	175.23	175.43	380

Table 8.1.21 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
390	175.43	175.64	175.84	176.04	176.25	176.45	176.66	176.86	177.06	177.27	177.47	390
400	177.47	177.68	177.88	178.08	178.29	178.49	178.70	178.90	179.10	179.31	179.51	400
410	179.51	179.71	179.92	180.12	180.32	180.53	180.73	180.93	181.14	181.34	181.54	410
420	181.54	181.75	181.95	182.15	182.36	182.56	182.76	182.97	183.17	183.37	183.57	420
430	183.57	183.78	183.98	184.18	184.39	184.59	184.79	184.99	185.20	185.40	185.60	430
440	185.60	185.80	186.01	186.21	186.41	186.61	186.82	187.02	187.22	187.42	187.62	440
450	187.62	187.83	188.03	188.23	188.43	188.63	188.84	189.04	189.24	189.44	189.64	450
460	189.64	189.85	190.05	190.25	190.45	190.65	190.85	191.06	191.26	191.46	191.66	460
470	191.66	191.86	192.06	192.26	192.47	192.67	192.87	193.07	193.27	193.47	193.67	470
480	193.67	193.87	194.07	194.28	194.48	194.68	194.88	195.08	195.28	195.48	195.68	480
490	195.68	195.88	196.08	196.28	196.48	196.68	196.88	197.09	197.29	197.49	197.69	490
500	197.69	197.89	198.09	198.29	198.49	198.69	198.89	199.09	199.29	199.49	199.69	500
510	199.69	199.89	200.09	200.29	200.49	200.69	200.89	201.09	201.29	201.49	201.69	510
520	201.69	201.89	202.09	202.28	202.48	202.68	202.88	203.08	203.28	203.48	203.68	520
530	203.68	203.88	204.08	204.28	204.48	204.68	204.88	205.07	205.27	205.47	205.67	530
540	205.67	205.87	206.07	206.27	206.47	206.67	206.86	207.06	207.26	207.46	207.66	540
550	207.66	207.86	208.06	208.25	208.45	208.65	208.85	209.05	209.25	209.44	209.64	550
560	209.64	209.84	210.04	210.24	210.44	210.63	210.83	211.03	211.23	211.43	211.62	560
570	211.62	211.82	212.02	212.22	212.41	212.61	212.81	213.01	213.20	213.40	213.60	570
580	213.60	213.80	213.99	214.19	214.39	214.59	214.78	214.98	215.18	215.38	215.57	580
590	215.57	215.77	215.97	216.16	216.36	216.56	216.76	216.95	217.15	217.35	217.54	590
600	217.54	217.74	217.94	218.13	218.33	218.53	218.72	218.92	219.12	219.31	219.51	600
610	219.51	219.70	219.90	220.10	220.29	220.49	220.69	220.88	221.08	221.27	221.47	610
620	221.47	221.67	221.86	22.06	222.25	222.45	222.65	222.84	223.04	223.23	223.43	620
630	223.43	223.63	223.82	224.02	224.21	224.41	224.60	224.80	224.99	225.19	225.38	630
640	225.38	225.58	225.78	225.97	226.17	226.36	226.56	226.75	226.95	227.14	227.34	640
650	227.34	227.53	227.73	227.92	228.12	228.31	228.51	228.70	228.89	229.09	229.28	650
660	229.28	229.48	229.67	229.87	230.06	230.26	230.45	230.65	230.84	231.03	231.23	660
670	231.23	231.42	231.62	231.81	232.01	232.20	232.39	232.59	232.78	232.98	233.17	670
680	233.17	233.36	233.56	233.75	233.94	234.14	234.33	234.53	234.72	234.91	235.11	680
690	235.11	235.30	235.49	235.69	235.88	236.07	236.27	236.46	236.65	236.85	237.04	690
700	237.04	237.23	237.43	237.62	237.81	238.01	238.20	238.39	238.58	238.78	238.97	700
710	238.97	239.16	239.36	239.55	239.74	239.93	240.13	240.32	240.51	240.70	240.90	710
720	240.90	241.09	241.28	241.47	241.67	241.86	242.05	242.24	242.44	242.63	242.82	720
730	242.82	243.01	243.20	243.40	243.59	243.78	243.97	244.16	244.36	244.55	244.74	730
740	244.74	244.93	245.12	245.31	245.51	245.70	245.89	246.08	246.27	246.46	246.65	740
750	246.65	246.85	247.04	247.23	247.42	247.61	247.80	247.99	248.18	248.38	248.57	750
760	248.57	248.76	248.95	249.14	249.33	249.52	249.71	249.90	250.09	250.28	250.48	760
770	250.48	250.67	250.86	251.05	251.24	251.43	251.62	251.81	252.00	252.19	252.38	770
780	252.38	252.57	252.76	252.95	253.14	253.33	253.52	253.71	253.90	254.09	254.28	780
790	254.28	254.47	254.66	254.85	255.04	255.23	255.42	255.61	255.80	255.99	256.18	790
800	256.18	256.37	256.56	256.75	256.94	257.13	257.32	257.51	257.70	257.88	258.07	800
810	258.07	258.26	258.45	258.64	258.83	259.02	259.21	259.40	259.59	259.78	259.96	810
820	259.96	260.15	260.34	260.53	260.72	260.91	261.10	261.29	261.47	261.66	261.85	820
830	261.85	262.04	262.23	262.42	262.61	262.79	262.98	263.17	263.36	263.55	263.74	830
840	263.74	263.92	264.11	264.30	264.49	264.68	264.86	265.05	265.24	265.43	265.62	840
850	265.62	265.80	265.99	266.18	266.37	266.55	266.74	266.93	267.12	267.30	267.49	850
860	267.49	267.68	267.87	268.05	268.24	268.43	268.62	268.80	268.99	269.18	269.36	860
870	269.36	269.55	269.74	269.93	270.11	270.30	270.49	270.67	270.86	271.05	271.23	870
880	271.23	271.42	271.61	271.79	271.98	272.17	272.35	272.54	272.73	272.91	273.10	880
890	273.10	273.29	273.47	273.66	273.84	274.03	274.22	274.40	274.59	274.78	274.96	890
900	274.96	275.15	275.33	275.52	275.71	275.89	276.08	276.26	276.45	276.63	276.82	900
910	276.82	277.01	277.19	277.38	277.56	277.75	277.93	278.12	278.30	278.49	278.67	910

Table 8.1.21 cont.   Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
920	278.67	278.86	279.05	279.23	279.42	279.60	279.79	279.97	280.16	280.34	280.53	920
930	280.53	280.71	280.90	281.08	281.27	281.45	281.64	281.82	282.00	282.19	282.37	930
940	282.37	282.56	282.74	282.93	283.11	283.30	283.48	283.67	283.85	284.03	284.22	940
950	284.22	284.40	284.59	284.77	284.95	285.14	285.32	285.51	285.69	285.87	286.06	950
960	286.06	286.24	286.43	286.61	286.79	286.98	287.16	287.34	287.53	287.71	287.90	960
970	287.90	288.08	288.26	288.45	288.63	288.81	289.00	289.18	289.36	289.55	289.73	970
980	289.73	289.91	290.10	290.28	290.46	290.64	290.83	291.01	291.19	291.38	291.56	980
990	291.56	291.74	291.92	292.11	292.29	292.47	292.65	292.84	293.02	293.20	293.38	990
1000	293.38	293.57	293.75	293.93	294.11	294.30	294.48	294.66	294.84	295.03	295.21	1000
1010	295.21	295.39	295.57	295.75	295.94	296.12	296.30	296.48	296.66	296.84	297.03	1010
1020	297.03	297.21	297.39	297.57	297.75	297.93	298.12	298.30	298.48	298.66	298.84	1020
1030	298.84	299.02	299.20	299.39	299.57	299.75	299.93	300.11	300.29	300.47	300.65	1030
1040	300.65	300.84	301.02	301.20	301.38	301.56	301.74	301.92	302.10	302.28	302.46	1040
1050	302.46	302.64	302.82	303.00	303.18	303.37	303.55	303.73	303.91	304.09	304.27	1050
1060	304.27	304.45	304.63	304.81	304.99	305.17	305.35	305.53	305.71	305.89	306.07	1060
1070	306.07	306.25	306.43	306.61	306.79	306.97	307.15	307.33	307.51	307.69	307.87	1070
1080	307.87	308.05	308.22	308.40	308.58	308.76	308.94	309.12	309.30	309.48	309.66	1080
1090	309.66	309.84	310.02	310.20	310.38	310.56	310.73	310.91	311.09	311.27	311.45	1090
1100	311.45	311.63	311.81	311.99	312.17	312.34	312.52	312.70	312.88	313.06	313.24	1100
1110	313.24	313.42	313.59	313.77	313.95	314.13	314.31	314.49	314.66	314.84	315.02	1110
1120	315.02	315.20	315.38	315.55	315.73	315.91	316.09	316.27	316.44	316.62	316.80	1120
1130	316.80	316.98	317.16	317.33	317.51	317.69	317.87	318.04	318.22	318.40	318.58	1130
1140	318.58	318.75	318.93	319.11	319.29	319.46	319.64	319.82	319.99	320.17	320.35	1140
1150	320.35	320.53	320.70	320.88	321.06	321.23	321.41	321.59	321.76	321.94	322.12	1150
1160	322.12	322.29	322.47	322.65	322.82	323.00	323.18	323.35	323.53	323.71	323.88	1160
1170	323.88	324.06	324.24	324.41	324.59	324.76	324.94	325.12	325.29	325.47	325.64	1170
1180	325.64	325.82	326.00	326.17	326.35	326.52	326.70	326.88	327.05	327.23	327.40	1180
1190	327.40	327.58	327.75	327.93	328.11	328.28	328.46	328.63	328.81	328.98	329.16	1190
1200	329.16	329.33	329.51	329.68	329.86	330.03	330.21	330.38	330.56	330.73	330.91	1200
1210	330.91	331.08	331.26	331.43	331.61	331.78	331.96	332.13	332.31	332.48	332.66	1210
1220	332.66	332.83	333.00	333.18	333.35	333.53	333.70	333.88	334.05	334.23	334.40	1220
1230	334.40	334.57	334.75	334.92	335.10	335.27	335.44	335.62	335.79	335.97	336.14	1230
1240	336.14	336.31	336.49	336.66	336.84	337.01	337.18	337.36	337.53	337.70	337.88	1240
1250	337.88	338.05	338.22	338.40	338.57	338.74	338.92	339.09	339.26	339.44	339.61	1250
1260	339.61	339.78	339.96	340.13	340.30	340.47	340.65	340.82	340.99	341.17	341.34	1260
1270	341.34	341.51	341.68	341.86	342.03	342.20	342.38	342.55	342.72	342.89	343.07	1270
1280	343.07	343.24	343.41	343.58	343.75	343.93	344.10	344.27	344.44	344.62	344.79	1280
1290	344.79	344.96	345.13	345.30	345.48	345.65	345.82	345.99	346.16	346.33	346.51	1290
1300	346.51	346.68	346.85	347.02	347.19	347.36	347.54	347.71	347.88	348.05	348.22	1300
1310	348.22	348.39	348.56	348.74	348.91	349.08	349.25	349.42	349.59	349.76	349.93	1310
1320	349.93	350.10	350.28	350.45	350.62	350.79	350.96	351.13	351.30	351.47	351.64	1320
1330	351.64	351.81	351.98	352.15	352.32	352.49	352.66	352.83	353.01	353.18	353.35	1330
1340	353.35	353.52	353.69	353.86	354.03	354.20	354.37	354.54	354.71	354.88	355.05	1340
1350	355.05	355.22	355.39	355.56	355.73	355.90	356.07	356.24	356.40	356.57	356.74	1350
1360	356.74	356.91	357.08	357.25	357.42	357.59	357.76	357.93	358.10	358.27	358.44	1360
1370	358.44	358.61	358.78	358.94	359.11	359.28	359.45	359.62	359.79	359.96	360.13	1370
1380	360.13	360.30	360.47	360.63	360.80	360.97	361.14	361.31	361.48	361.65	361.81	1380
1390	361.81	361.98	362.15	362.32	362.49	362.66	362.82	362.99	363.16	363.33	363.50	1390
1400	363.50	363.67	363.83	364.00	364.17	364.34	364.51	364.67	364.84	365.01	365.18	1400
1410	365.18	365.34	365.51	365.68	365.85	366.01	366.18	366.35	366.52	366.68	366.85	1410
1420	366.85	367.02	367.19	367.35	367.52	367.69	367.86	368.02	368.19	368.36	368.52	1420
1430	368.52	368.69	368.86	369.03	369.19	369.36	369.53	369.69	369.86	370.03	370.19	1430
1440	370.19	370.36	370.53	370.69	370.86	371.03	371.19	371.36	371.53	371.69	371.86	1440

Table 8.1.21 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1450	371.86	372.02	372.19	372.36	372.52	372.69	372.86	373.02	373.19	373.35	373.52	1450
1460	373.52	373.69	373.85	374.02	374.18	374.35	374.51	374.68	374.85	375.01	375.18	1460
1470	375.18	375.34	375.51	375.67	375.84	376.01	376.17	376.34	376.50	376.67	376.83	1470
1480	376.83	377.00	377.16	377.33	377.49	377.66	377.82	377.99	378.15	378.32	378.48	1480
1490	378.48	378.65	378.81	378.98	379.14	379.31	379.47	379.64	379.80	379.97	380.13	1490
1500	380.13	380.29	380.46	380.62	380.79	380.95	381.12	381.28	381.45	381.61	381.77	1500
1510	381.77	381.94	382.10	382.27	382.43	382.59	382.76	382.92	383.09	383.25	383.41	1510
1520	383.41	383.58	383.74	383.90	384.07	384.23	384.40	384.56	384.72	384.89	385.05	1520
1530	385.05	385.21	385.38	385.54	385.70	385.87	386.03	386.19	386.36	386.52	386.68	1530
1540	386.68	386.85	387.01	387.17	387.33	387.50	387.66	387.82	387.99	388.15	388.31	1540
1550	388.31	388.47	388.64	388.80	388.96	389.13	389.29	389.45	389.61	389.78	389.94	1550
1560	389.94	390.10	390.26									1560

Platinum 100, Alpha = 0.00392

Resistance as a Function of Temperature (°C)
Reference Standard: JIS C 1604

Table 8.1.22 Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-200	17.14	17.57	18.00	18.43	18.87	19.30	19.73	20.17	20.60	21.03	21.47	-200
-190	21.47	21.90	22.33	22.77	23.20	23.63	24.07	24.50	24.93	25.37	25.80	-190
-180	25.80	26.23	26.66	27.10	27.53	27.96	28.39	28.82	29.26	29.69	30.12	-180
-170	30.12	30.55	30.98	31.41	31.84	32.27	32.70	33.13	33.56	33.99	34.41	-170
-160	34.41	34.84	35.27	35.70	36.12	36.55	36.98	37.40	37.83	38.26	38.68	-160
-150	38.68	39.11	39.53	39.95	40.38	40.80	41.22	41.65	42.07	42.49	42.91	-150
-140	42.91	43.34	43.76	44.18	44.60	45.02	45.44	45.86	46.28	46.70	47.12	-140
-130	47.12	47.53	47.95	48.37	48.79	49.20	49.62	50.04	50.45	50.87	51.29	-130
-120	51.29	51.70	52.12	52.53	52.95	53.36	53.78	54.19	54.61	55.02	55.44	-120
-110	55.44	55.85	56.26	56.68	57.09	57.50	57.92	58.33	58.75	59.16	59.57	-110
-100	59.57	59.98	60.39	60.80	61.22	61.63	62.04	62.45	62.86	63.27	63.68	-100
-90	63.68	64.09	64.50	64.91	65.32	65.73	66.14	66.55	66.95	67.36	67.77	-90
-80	67.77	68.18	68.59	69.00	69.40	69.81	70.22	70.63	71.03	71.44	71.85	-80
-70	71.85	72.26	72.66	73.07	73.48	73.88	74.29	74.69	75.10	75.50	75.91	-70
-60	75.91	76.32	76.72	77.13	77.53	77.94	78.34	78.74	79.15	79.55	79.96	-60
-50	79.96	80.36	80.77	81.17	81.57	81.98	82.38	82.78	83.19	83.59	83.99	-50
-40	83.99	84.39	84.80	85.20	85.60	86.00	86.41	86.81	87.21	87.61	88.01	-40
-30	88.01	88.41	88.81	89.22	89.62	90.02	90.42	90.82	91.22	91.62	92.02	-30
-20	92.02	92.42	92.82	93.22	93.62	94.02	94.42	94.82	95.22	95.62	96.02	-20
-10	96.02	96.42	96.81	97.21	97.61	98.01	98.41	98.81	99.21	99.60	100.00	-10
0	100.00	100.40	100.79	101.19	101.59	101.99	102.38	102.78	103.18	103.57	103.97	0
10	103.97	104.37	104.76	105.16	105.56	105.95	106.35	106.74	107.14	107.54	107.93	10
20	107.93	108.33	108.72	109.12	109.51	109.91	110.30	110.69	111.09	111.48	111.88	20
30	111.88	112.27	112.66	113.06	113.45	113.85	114.24	114.63	115.02	115.42	115.81	30
40	115.81	116.20	116.60	116.99	117.38	117.77	118.16	118.56	118.95	119.34	119.73	40
50	119.73	120.12	120.51	120.91	121.30	121.69	122.08	122.47	122.86	123.25	123.64	50
60	123.64	124.03	124.42	124.81	125.20	125.59	125.98	126.37	126.76	127.15	127.54	60
70	127.54	127.93	128.32	128.70	129.09	129.48	129.87	130.26	130.65	131.04	131.42	70
80	131.42	131.81	132.20	132.59	132.97	133.36	133.75	134.14	134.52	134.91	135.30	80
90	135.30	135.68	136.07	136.46	136.84	137.23	137.62	138.00	138.39	138.77	139.16	90
100	139.16	139.55	139.93	140.32	140.70	141.09	141.47	141.86	142.24	142.63	143.01	100
110	143.01	143.39	143.78	144.16	144.55	144.93	145.31	145.70	146.08	146.46	146.85	110

Table 8.1.22 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
120	146.85	147.23	147.61	148.00	148.38	148.76	149.14	149.53	149.91	150.29	150.67	120
130	150.67	151.06	151.44	151.82	152.20	152.58	152.96	153.34	153.73	154.11	154.49	130
140	154.49	154.87	155.25	155.63	156.01	156.39	156.77	157.15	157.53	157.91	158.29	140
150	158.29	158.67	159.05	159.43	159.81	160.19	160.57	160.94	161.32	161.70	162.08	150
160	162.08	162.46	162.84	163.22	163.59	163.97	164.35	164.73	165.10	165.48	165.86	160
170	165.86	166.24	166.61	166.99	167.37	167.75	168.12	168.50	168.87	169.25	169.63	170
180	169.63	170.00	170.38	170.76	171.13	171.51	171.88	172.26	172.63	173.01	173.38	180
190	173.38	173.76	174.13	174.51	174.88	175.26	175.63	176.01	176.38	176.75	177.13	190
200	177.13	177.50	177.88	178.25	178.62	179.00	179.37	179.74	180.11	180.49	180.86	200
210	180.86	181.23	181.61	181.98	182.35	182.72	183.09	183.47	183.84	184.21	184.58	210
220	184.58	184.95	185.32	185.70	186.07	186.44	186.81	187.18	187.55	187.92	188.29	220
230	188.29	188.66	189.03	189.40	189.77	190.14	190.51	190.88	191.25	191.62	191.99	230
240	191.99	192.36	192.72	193.09	193.46	193.83	194.20	194.57	194.94	195.30	195.67	240
250	195.67	196.04	196.41	196.78	197.14	197.51	197.88	198.25	198.61	198.98	199.35	250
260	199.35	199.71	200.08	200.45	200.81	201.18	201.55	201.91	202.28	202.64	203.01	260
270	203.01	203.38	203.74	204.11	204.47	204.84	205.20	205.57	205.93	206.30	206.66	270
280	206.66	207.03	207.39	207.75	208.12	208.48	208.85	209.21	209.57	209.94	210.30	280
290	210.30	210.66	211.03	211.39	211.75	212.12	212.48	212.84	213.20	213.57	213.93	290
300	213.93	214.29	214.65	215.01	215.38	215.74	216.10	216.46	216.82	217.18	217.54	300
310	217.54	217.90	218.27	218.63	218.99	219.35	219.71	220.07	220.43	220.79	221.15	310
320	221.15	221.51	221.87	222.23	222.59	222.95	223.30	223.66	224.02	224.38	224.74	320
330	224.74	225.10	225.46	225.82	226.17	226.53	226.89	227.25	227.61	227.96	228.32	330
340	228.32	228.68	229.04	229.39	229.75	230.11	230.46	230.82	231.18	231.53	231.89	340
350	231.89	232.25	232.60	232.96	233.31	233.67	234.03	234.38	234.74	235.09	235.45	350
360	235.45	235.80	236.16	236.51	236.87	237.22	237.58	237.93	238.29	238.64	238.99	360
370	238.99	239.35	239.70	240.06	240.41	240.76	241.12	241.47	241.82	242.18	242.53	370
380	242.53	242.88	243.23	243.59	243.94	244.29	244.64	244.99	245.35	245.70	246.05	380
390	246.05	246.40	246.75	247.10	247.46	247.81	248.16	248.51	248.86	249.21	249.56	390
400	249.56	249.91	250.26	250.61	250.96	251.31	251.66	252.01	252.36	252.71	253.06	400
410	253.06	253.41	253.76	254.11	254.46	254.81	255.15	255.50	255.85	256.20	256.55	410
420	256.55	256.90	257.24	257.59	257.94	258.29	258.63	258.98	259.33	259.68	260.02	420
430	260.02	260.37	260.72	261.06	261.41	261.76	262.10	262.45	262.79	263.14	263.49	430
440	263.49	263.83	264.18	264.52	264.87	265.21	265.56	265.90	266.25	266.59	266.94	440
450	266.94	267.28	267.63	267.97	268.32	268.66	269.00	269.35	269.69	270.03	270.38	450
460	270.38	270.72	271.06	271.41	271.75	272.09	272.44	272.78	273.12	273.46	273.81	460
470	273.81	274.15	274.49	274.83	275.17	275.52	275.86	276.20	276.54	276.88	277.22	470
480	277.22	277.56	277.90	278.25	278.59	278.93	279.27	279.61	279.95	280.29	280.63	480
490	280.63	280.97	281.31	281.65	281.99	282.32	282.66	283.00	283.34	283.68	284.02	490
500	284.02	284.36	284.70	285.04	285.37	285.71	286.05	286.39	286.72	287.06	287.40	500
510	287.40	287.74	288.07	288.41	288.75	289.09	289.42	289.76	290.10	290.43	290.77	510
520	290.77	291.10	291.44	291.78	292.11	292.45	292.78	293.12	293.45	293.79	294.12	520
530	294.12	294.46	294.79	295.13	295.46	295.80	296.13	296.47	296.80	297.13	297.47	530
540	297.47	297.80	298.14	298.47	298.80	299.14	299.47	299.80	300.13	300.47	300.80	540
550	300.80	301.13	301.47	301.80	302.13	302.46	302.79	303.13	303.46	303.79	304.12	550
560	304.12	304.45	304.78	305.11	305.44	305.78	306.11	306.44	306.77	307.10	307.43	560
570	307.43	307.76	308.09	308.42	308.75	309.08	309.41	309.74	310.07	310.39	310.72	570
580	310.72	311.05	311.38	311.71	312.04	312.37	312.70	313.02	313.35	313.68	314.01	580
590	314.01	314.34	314.66	314.99	315.32	315.64	315.97	316.30	316.63	316.95	317.28	590
600	317.28	317.61	317.93	318.26	318.58	318.91	319.24	319.56	319.89	320.21	320.54	600
610	320.54	320.86	321.19	321.51	321.84	322.16	322.49	322.81	323.14	323.46	323.78	610
620	323.78	324.11	324.43	324.76	325.08	325.40	325.73	326.05	326.37	326.70	327.02	620
630	327.02	327.34	327.66	327.99	328.31	328.63	328.95	329.28	329.60	329.92	330.24	630
640	330.24	330.56	330.88	331.20	331.53	331.85	332.17	332.49	332.81	333.13		640

Platinum 100, Alpha = 0.00392

Resistance as a Function of Temperature (°F)
Reference Standard: JIS C 1604

Table 8.1.23 Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-330			17.14	17.38	17.62	17.86	18.10	18.34	18.58	18.82	19.06	-330
-320	19.06	19.30	19.54	19.78	20.02	20.26	20.50	20.75	20.99	21.23	21.47	-320
-310	21.47	21.71	21.95	22.19	22.43	22.67	22.91	23.15	23.39	23.63	23.87	-310
-300	23.87	24.12	24.36	24.60	24.84	25.08	25.32	25.56	25.80	26.04	26.28	-300
-290	26.28	26.52	26.75	27.00	27.24	27.48	27.72	27.96	28.20	28.44	28.68	-290
-280	28.68	28.92	29.16	29.40	29.64	29.88	30.12	30.36	30.60	30.84	31.07	-280
-270	31.07	31.31	31.55	31.79	32.03	32.27	32.51	32.75	32.99	33.22	33.46	-270
-260	33.46	33.70	33.94	34.18	34.41	34.65	34.89	35.13	35.37	35.60	35.84	-260
-250	35.84	36.08	36.31	36.55	36.79	37.03	37.26	37.50	37.74	37.97	38.21	-250
-240	38.21	38.44	38.68	38.92	39.15	39.39	39.62	39.86	40.10	40.33	40.57	-240
-230	40.57	40.80	41.04	41.27	41.51	41.74	41.98	42.21	42.45	42.68	42.91	-230
-220	42.91	43.15	43.38	43.62	43.85	44.08	44.32	44.55	44.79	45.02	45.25	-220
-210	45.25	45.49	45.72	45.95	46.18	46.42	46.65	46.88	47.12	47.35	47.58	-210
-200	47.58	47.81	48.04	48.28	48.51	48.74	48.97	49.20	49.44	49.67	49.90	-200
-190	49.90	50.13	50.36	50.59	50.82	51.06	51.29	51.52	51.75	51.98	52.21	-190
-180	52.21	52.44	52.67	52.90	53.13	53.36	53.59	53.82	54.05	54.28	54.52	-180
-170	54.52	54.75	54.98	55.21	55.44	55.67	55.90	56.13	56.36	56.59	56.82	-170
-160	56.82	57.05	57.28	57.50	57.73	57.96	58.19	58.42	58.65	58.88	59.11	-160
-150	59.11	59.64	59.57	59.80	60.03	60.26	60.48	60.71	60.94	61.17	61.40	-150
-140	61.40	61.63	61.86	62.08	62.31	62.54	62.77	63.00	63.22	63.45	63.68	-140
-130	63.68	63.91	64.14	64.36	64.59	64.82	65.05	65.27	65.50	65.73	65.96	-130
-120	65.96	66.18	66.41	66.64	66.86	67.09	67.32	67.55	67.77	68.00	68.23	-120
-110	68.23	68.45	68.68	68.91	69.13	69.36	69.59	69.81	70.04	70.27	70.49	-110
-100	70.49	70.72	70.94	71.17	71.40	71.62	71.85	72.07	72.30	72.53	72.75	-100
-90	72.75	72.98	73.20	73.43	73.66	73.88	74.11	74.33	74.56	74.78	75.01	-90
-80	75.01	75.23	75.46	75.68	75.91	76.14	76.36	76.59	76.81	77.04	77.26	-80
-70	77.26	77.49	77.71	77.94	78.16	78.39	78.61	78.83	79.06	79.28	79.51	-70
-60	79.51	79.73	79.96	80.18	80.41	80.63	80.85	81.08	81.30	81.53	81.75	-60
-50	81.75	81.98	82.20	82.42	82.65	82.87	83.10	83.32	83.54	83.77	83.99	-50
-40	83.99	84.21	84.44	84.66	84.89	85.11	85.33	85.56	85.78	86.00	86.23	-40
-30	86.23	86.45	86.67	86.90	87.12	87.34	87.57	87.79	88.01	88.24	88.46	-30
-20	88.46	88.68	88.90	89.13	89.35	89.57	89.80	90.02	90.24	90.46	90.69	-20
-10	90.69	90.91	91.13	91.35	91.58	91.80	92.02	92.24	92.47	92.69	92.91	-10
0	92.91	93.13	93.35	93.58	93.80	94.02	94.24	94.46	94.69	94.91	95.13	0
10	95.13	95.35	95.57	95.80	96.02	96.24	96.46	96.68	96.90	97.12	97.35	10
20	97.35	97.57	97.79	98.01	98.23	98.45	98.67	98.90	99.12	99.34	99.56	20
30	99.56	99.78	100.00	100.22	100.44	100.66	100.88	101.10	101.32	101.55	101.77	30
40	101.77	101.99	102.31	102.43	102.65	102.87	103.09	103.31	103.53	103.75	103.97	40
50	103.97	104.19	101.41	104.63	104.85	105.07	105.29	105.51	105.73	105.95	106.17	50
60	106.17	106.39	106.61	106.83	107.05	107.27	107.49	107.71	107.93	108.15	108.37	60
70	108.37	108.59	108.81	109.03	109.25	109.47	109.69	109.91	110.12	110.34	110.56	70
80	110.56	110.78	111.00	111.22	111.44	111.66	111.88	112.10	112.31	112.53	112.75	80
90	112.75	112.97	113.19	113.41	113.63	113.85	114.06	114.28	114.50	114.72	114.94	90
100	114.94	115.16	115.37	115.59	115.81	116.03	116.25	116.46	116.68	116.90	117.12	100
110	117.12	117.34	117.55	117.77	117.99	118.21	118.43	118.64	118.86	119.08	119.30	110
120	119.30	119.51	119.73	119.95	120.17	120.38	120.60	120.82	121.04	121.25	121.47	120
130	121.47	121.69	121.90	122.12	122.34	122.56	122.88	122.99	123.21	123.42	123.64	130
140	123.64	123.86	124.08	124.29	124.51	124.72	124.94	125.16	125.37	125.59	125.81	140

Table 8.1.23 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
150	125.81	126.02	126.24	126.46	126.67	126.89	127.11	127.32	127.54	127.75	127.97	150
160	127.97	128.19	128.40	128.62	128.83	129.05	129.27	129.48	129.70	129.91	130.13	160
170	130.13	130.35	130.56	130.78	130.99	131.21	131.42	131.64	131.85	132.07	132.29	170
180	132.29	132.50	132.72	132.93	133.15	133.36	133.58	133.79	134.01	134.22	134.44	180
190	134.44	134.65	134.87	135.08	135.30	135.51	135.73	135.94	136.16	136.37	136.59	190
200	136.59	136.80	137.02	137.23	137.45	137.66	137.87	138.09	138.30	138.52	138.73	200
210	138.73	138.95	139.16	139.37	139.59	139.80	140.02	140.23	140.44	140.66	140.87	210
220	140.87	141.09	141.30	141.51	141.73	141.94	142.16	142.37	142.58	142.80	143.01	220
230	143.01	143.22	143.44	143.65	143.86	144.08	144.29	144.50	144.72	144.93	145.14	230
240	145.14	145.36	145.57	145.78	146.00	146.21	146.42	146.64	146.85	147.06	147.27	240
250	147.27	147.49	147.70	147.91	148.12	148.34	148.55	148.76	148.97	149.19	149.40	250
260	149.40	149.61	149.82	150.04	150.25	150.46	150.67	150.89	151.10	151.31	151.52	260
270	151.52	151.73	151.95	152.16	152.37	152.58	152.79	153.01	153.22	153.43	153.64	270
280	153.64	153.85	154.06	154.28	154.49	154.70	154.91	155.12	155.33	155.55	155.76	280
290	155.76	155.97	156.18	156.37	156.60	156.81	157.02	157.24	157.45	157.66	157.87	290
300	157.87	158.08	158.29	158.50	158.71	158.92	159.13	159.34	159.55	159.77	159.98	300
310	159.98	160.19	160.40	160.61	160.82	161.03	161.24	161.45	161.66	161.87	162.08	310
320	162.08	162.29	162.50	162.71	162.92	163.13	163.34	163.55	163.76	163.97	164.18	320
330	164.18	164.39	164.60	164.81	165.02	165.23	165.44	165.65	165.86	166.07	166.28	330
340	166.28	166.49	166.70	166.91	167.12	167.33	167.54	167.75	167.95	168.16	168.37	340
350	168.37	168.58	168.79	169.00	169.21	169.42	169.63	169.84	170.05	170.25	170.46	350
360	170.46	170.67	170.88	171.09	171.30	171.51	171.72	171.92	172.13	172.34	172.55	360
370	172.55	172.76	172.97	173.18	173.38	173.59	173.80	174.01	174.22	174.42	174.63	370
380	174.63	174.84	175.05	175.26	175.47	175.67	175.88	176.09	176.30	176.50	176.71	380
390	176.71	176.92	177.13	177.34	177.54	177.75	177.96	178.17	178.37	178.58	178.79	390
400	178.79	179.00	179.20	179.41	179.62	179.82	180.03	180.24	180.45	180.65	180.86	400
410	180.86	181.07	181.27	181.48	181.69	181.90	182.10	182.31	182.52	182.72	182.93	410
420	182.93	183.14	183.34	183.55	183.76	183.96	184.17	184.38	184.58	184.79	184.99	420
430	184.99	185.20	185.41	185.61	185.82	186.03	186.23	186.44	186.64	186.85	187.06	430
440	187.06	187.26	187.47	187.67	187.88	188.08	188.29	188.50	188.70	188.91	189.11	440
450	189.11	189.32	189.52	189.73	189.93	190.14	190.35	190.55	190.76	190.96	191.17	450
460	191.17	191.37	191.58	191.78	191.99	192.19	192.40	192.60	192.81	193.01	193.22	460
470	193.22	193.42	193.63	193.83	194.04	194.24	194.44	194.65	194.85	195.06	195.26	470
480	195.26	196.47	195.67	195.88	196.08	196.29	196.49	196.69	196.90	197.10	197.31	480
490	197.31	197.51	197.72	197.92	198.12	198.33	198.53	198.74	198.94	199.14	199.35	490
500	199.35	199.55	199.75	199.96	200.16	200.37	200.57	200.77	200.98	201.18	201.38	500
510	201.38	201.59	201.79	201.99	202.20	202.40	202.60	202.81	203.01	203.21	203.42	510
520	203.42	203.63	203.82	204.03	204.23	204.43	204.63	204.84	205.04	205.24	205.45	520
530	205.45	205.65	205.85	206.05	206.26	206.46	206.66	206.86	207.07	207.27	207.47	530
540	207.47	207.67	207.88	208.08	208.28	208.48	208.68	208.89	209.09	209.29	209.49	540
550	209.49	209.69	209.90	210.10	210.30	210.50	210.70	210.91	211.11	211.31	211.51	550
560	211.51	211.71	211.91	212.12	212.32	212.52	212.72	212.92	213.12	213.32	213.53	560
570	213.53	21.73	213.93	214.13	214.33	214.53	214.73	217.93	215.13	215.34	215.54	570
580	215.54	215.74	215.94	216.14	216.34	216.54	216.74	216.94	217.14	217.34	217.54	580
590	217.54	217.74	217.94	218.15	218.35	218.55	218.75	218.95	219.15	219.35	219.55	590
600	219.55	219.75	219.95	220.15	220.35	220.55	220.75	220.95	221.15	221.35	221.55	600
610	221.55	221.75	221.95	222.15	222.35	222.55	222.75	222.95	223.15	223.34	223.54	610
620	223.54	223.74	223.94	224.14	224.34	224.54	224.74	224.94	225.14	225.34	225.54	620
630	225.54	225.74	225.94	226.13	226.33	226.53	226.73	226.93	227.13	227.33	227.53	630
640	227.53	227.73	227.92	228.12	228.32	228.52	228.72	228.92	229.12	229.31	229.51	640
650	229.51	229.71	229.91	230.11	230.31	230.50	230.70	230.90	231.10	231.30	231.49	650
660	231.49	231.69	231.89	232.09	232.29	232.48	232.68	232.88	233.08	233.28	233.47	660
670	233.47	233.67	233.87	234.07	234.26	234.46	234.66	234.86	235.05	235.25	235.45	670

Table 8.1.23 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
680	235.45	235.65	235.84	236.04	236.24	236.43	236.63	236.83	237.03	237.22	237.42	680
690	237.42	237.62	237.81	238.01	238.21	238.40	238.60	238.80	238.99	239.19	239.39	690
700	239.39	239.58	239.78	239.98	240.17	240.37	240.57	240.76	240.96	241.15	241.35	700
710	241.35	241.55	241.74	241.94	242.14	242.33	242.53	242.72	242.92	243.12	243.31	710
720	243.31	243.51	243.70	243.90	244.09	244.29	244.49	244.68	244.88	245.07	245.27	720
730	245.27	245.46	245.66	245.85	246.05	246.25	246.44	246.64	246.83	247.03	247.22	730
740	247.22	247.42	247.61	247.81	248.00	248.20	248.39	248.59	248.78	248.98	249.17	740
750	249.17	249.37	249.56	249.76	249.95	250.15	250.34	250.53	250.73	250.92	251.12	750
760	251.12	251.31	251.51	251.70	251.89	252.09	252.28	252.48	252.67	252.87	253.06	760
770	253.06	253.25	253.45	253.64	253.84	254.03	254.22	254.42	254.61	254.81	255.00	770
780	255.00	255.19	255.39	255.58	255.77	255.94	256.16	256.35	256.55	256.74	256.93	780
790	256.93	257.13	257.32	257.52	257.71	257.90	258.09	258.29	258.48	258.67	258.87	790
800	258.87	259.06	259.25	259.44	259.64	259.83	260.02	260.22	260.41	260.60	260.79	800
810	260.79	260.99	261.18	261.37	261.56	261.76	61.95	262.15	262.33	262.53	262.72	810
820	262.72	262.91	263.10	263.29	263.49	263.68	263.87	264.06	264.25	264.45	264.64	820
30	264.64	264.83	265.02	265.21	265.41	265.60	265.79	265.98	266.17	266.36	266.56	30
40	266.56	266.75	266.94	267.13	267.32	267.51	267.70	267.89	268.09	268.28	268.47	40
50	268.47	268.66	268.85	269.04	269.23	269.42	269.61	269.81	270.00	270.19	270.38	50
860	270.38	270.57	270.76	270.95	271.14	271.33	271.52	271.71	271.90	272.09	272.28	860
870	272.28	272.47	272.67	272.86	273.05	273.24	273.43	273.62	273.81	274.00	274.19	870
880	274.19	274.38	274.57	274.76	274.95	275.14	275.33	275.52	275.71	275.90	276.09	880
890	276.09	276.27	276.46	276.65	276.84	277.03	277.22	277.41	277.60	277.79	277.98	890
900	277.98	278.17	278.36	278.55	278.74	278.93	279.12	279.30	279.49	279.68	279.87	900
910	279.87	280.06	280.25	280.44	280.63	280.82	281.00	281.19	281.38	281.57	281.76	910
920	281.76	281.95	282.14	282.32	282.51	282.70	282.89	283.08	283.27	283.45	283.64	920
930	283.64	283.83	284.02	284.21	284.40	284.58	284.77	284.96	285.15	285.34	285.52	930
940	285.52	285.71	285.90	286.09	286.27	286.46	286.65	286.84	287.02	287.21	287.40	940
950	287.40	287.59	287.77	287.96	288.15	288.34	288.52	288.71	288.90	289.09	289.27	950
960	289.27	289.46	289.65	289.83	290.02	290.21	290.39	290.58	290.77	290.95	291.14	960
970	291.14	291.33	291.51	291.70	291.89	292.07	292.26	292.45	292.63	292.82	293.01	970
980	293.01	293.19	293.38	293.57	293.75	293.94	294.12	294.31	294.50	294.68	294.87	980
990	294.87	295.05	295.24	295.43	295.61	295.80	295.98	296.17	296.35	296.54	296.73	990
1000	296.73	296.91	297.10	297.28	297.47	297.65	297.84	298.02	298.21	298.39	298.58	1000
1010	298.58	298.77	298.95	299.14	299.32	299.51	299.69	299.88	300.06	300.25	300.43	1010
1020	300.43	300.62	600.80	300.98	301.17	301.35	301.54	301.72	301.91	302.09	302.28	1020
1030	302.28	302.46	302.65	302.83	303.01	303.20	303.38	303.57	303.75	303.94	304.12	1030
1040	304.12	304.30	304.49	304.67	304.86	305.04	305.22	305.41	305.59	305.78	305.96	1040
1050	305.96	306.14	306.33	306.51	306.69	306.88	307.06	307.24	307.43	307.61	307.79	1050
1060	307.79	307.98	308.16	308.34	308.53	308.71	308.89	309.08	309.26	309.44	309.63	1060
1070	309.63	309.81	309.99	310.18	310.36	310.54	310.72	310.91	311.09	311.27	311.45	1070
1080	311.45	311.64	311.82	312.00	312.18	312.37	312.55	312.73	312.91	313.10	313.28	1080
1090	313.28	313.46	313.64	313.83	314.01	314.19	314.37	314.55	314.74	314.92	315.10	1090
1100	315.10	315.28	315.46	315.64	315.83	316.01	316.19	316.37	316.55	316.73	316.92	1100
1110	316.92	317.10	317.28	317.46	317.64	317.82	318.00	318.19	318.37	318.55	318.73	1110
1120	318.73	318.91	319.09	319.27	319.45	319.63	319.81	320.00	320.18	320.36	320.54	1120
1130	320.54	320.72	320.90	321.08	321.26	321.44	321.62	321.80	321.98	322.16	322.34	1130
1140	322.34	322.52	322.70	322.88	323.06	323.24	323.42	323.60	323.78	323.96	324.14	1140
1150	324.14	324.32	324.50	324.68	324.86	325.04	325.22	325.40	325.58	325.76	325.94	1150
1160	325.94	326.12	326.30	326.48	326.66	326.84	327.02	327.20	327.38	327.56	327.74	1160
1170	327.74	327.91	328.09	328.27	328.45	328.63	328.81	328.99	329.17	329.35	329.53	1170
1180	329.53	329.70	329.88	330.06	330.24	330.42	330.60	330.78	330.95	331.13	331.31	1180
1190	331.31	331.49	331.67	331.85	332.02	332.20	332.38	332.56	332.74	332.92	333.09	1190
1200	333.09											1200

Platinum 200, Alpha = 0.00385

Resistance as a Function of Temperature (°C)
Reference Standard: IEC 751

Table 8.1.24 Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-200	36.99	37.85	38.72	39.58	40.44	41.31	42.17	43.03	43.89	44.75	45.61	-200
-190	45.61	46.46	47.32	48.18	49.03	49.89	50.74	51.60	52.45	53.30	54.16	-190
-180	54.16	55.01	55.86	56.71	57.56	58.41	59.25	60.10	60.95	61.79	62.64	-180
-170	62.64	63.48	64.33	65.17	66.02	66.86	67.70	68.54	69.38	70.22	71.06	-170
-160	71.06	71.90	72.74	73.58	74.42	75.25	76.09	76.92	77.76	78.59	79.43	-160
-150	79.43	80.26	81.09	81.93	82.76	83.59	84.42	85.25	86.08	86.91	87.74	-150
-140	87.74	88.57	89.39	90.22	91.05	91.87	92.70	93.53	94.35	95.17	96.00	-140
-130	96.00	96.82	97.64	98.47	99.29	100.11	100.93	101.75	102.57	103.39	104.21	-130
-120	104.21	105.03	105.85	106.67	107.48	108.30	109.12	109.93	110.75	111.57	112.38	-120
-110	112.38	113.20	114.01	114.82	115.64	116.45	117.26	118.07	118.89	119.70	120.51	-110
-100	120.51	121.32	122.13	122.94	123.75	124.56	125.37	126.17	126.98	127.79	128.60	-100
-90	128.60	129.40	130.21	131.02	131.82	132.63	133.43	134.24	135.04	135.85	136.65	-90
-80	136.65	137.45	138.26	139.06	139.86	140.66	141.47	142.27	143.07	143.87	144.67	-80
-70	144.67	145.47	146.27	147.07	147.87	148.67	149.47	150.26	151.06	151.86	152.66	-70
-60	152.66	153.45	154.25	155.05	155.84	156.64	157.43	158.23	159.02	159.82	160.61	-60
-50	160.61	161.41	162.20	163.00	163.79	164.58	165.37	166.17	166.96	167.75	168.54	-50
-40	168.54	169.33	170.13	170.92	171.71	172.50	173.29	174.08	174.87	175.66	176.44	-40
-30	176.44	177.23	178.02	178.81	179.60	180.39	181.17	181.96	182.75	183.53	184.32	-30
-20	184.32	185.11	185.89	186.68	187.46	188.25	189.03	189.82	190.60	191.39	192.17	-20
-10	192.17	192.96	193.74	194.52	195.31	196.09	196.87	197.65	198.44	199.22	200.00	-10
0	200.00	200.78	201.56	202.34	203.12	203.91	204.69	205.47	206.25	207.03	207.80	0
10	207.80	208.58	209.36	210.14	210.92	211.70	212.48	213.25	214.03	214.81	215.59	10
20	215.59	216.36	217.14	217.92	218.69	219.47	220.24	221.02	221.79	222.57	223.34	20
30	223.34	224.12	224.89	225.67	226.44	227.21	227.99	228.76	229.53	230.31	231.08	30
40	231.08	231.85	232.62	233.39	234.17	234.94	235.71	236.48	237.25	238.02	238.79	40
50	238.79	239.56	240.33	241.10	241.87	242.64	243.41	244.17	244.94	245.71	246.48	50
60	246.48	247.25	248.01	248.78	249.55	250.31	251.08	251.85	252.61	253.38	254.14	60
70	254.14	254.91	255.67	256.44	257.20	257.97	258.73	259.50	260.26	261.02	261.79	70
80	261.79	262.55	263.31	264.07	264.84	265.60	266.36	267.12	267.88	268.64	269.40	80
90	269.40	270.17	270.93	271.69	272.45	273.21	273.96	274.72	275.48	276.24	277.00	90
100	277.00	277.76	278.52	279.27	280.03	280.79	281.55	282.30	283.06	283.82	284.57	100
110	284.57	285.33	286.08	286.84	287.59	288.35	289.10	289.86	290.61	291.37	292.12	110
120	292.12	292.88	293.63	294.38	295.13	295.89	296.64	297.39	298.14	298.90	299.65	120
130	299.65	300.40	301.15	301.90	302.65	303.40	304.15	304.90	305.65	306.40	307.15	130
140	307.15	307.90	308.65	309.40	310.14	310.89	311.64	312.39	313.14	313.88	314.63	140
150	314.63	315.38	316.12	316.87	317.62	318.36	319.11	319.85	320.60	321.34	322.09	150
160	322.09	322.83	323.57	324.32	325.06	325.81	326.55	327.29	328.03	328.78	329.52	160
170	329.52	330.26	331.00	331.74	332.49	333.23	333.97	334.71	335.45	336.19	336.93	170
180	336.93	337.67	338.41	339.15	339.89	340.63	341.36	342.10	342.84	343.58	344.32	180
190	344.32	345.05	345.79	346.53	347.26	348.00	348.74	349.47	350.21	350.94	351.68	190
200	351.68	352.41	353.15	353.88	354.62	355.35	356.09	356.82	357.55	358.29	359.02	200
210	359.02	359.75	360.48	361.22	361.95	362.68	363.41	364.14	364.87	365.61	366.34	210
220	366.34	367.07	367.80	368.53	369.26	369.99	370.72	371.44	372.17	372.90	373.63	220
230	373.63	374.36	375.09	375.81	376.54	377.27	378.00	378.72	379.45	380.18	380.90	230
240	380.90	381.63	382.35	383.08	383.80	384.53	385.25	385.98	386.70	387.42	388.15	240
250	388.15	388.87	389.60	390.32	391.04	391.76	392.49	393.21	393.93	394.65	395.37	250
260	395.37	396.09	396.81	397.54	398.26	398.98	399.70	400.42	401.14	401.85	402.57	260

Table 8.1.24 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
270	402.57	403.29	404.01	404.73	405.45	406.17	406.88	407.60	408.32	409.03	409.75	270
280	409.75	410.47	411.18	411.90	412.62	413.33	414.05	414.76	415.48	416.19	416.91	280
290	416.91	417.62	418.33	419.05	419.76	420.47	421.19	421.90	422.61	423.33	424.04	290
300	424.04	424.75	425.46	426.17	426.88	427.59	428.31	429.02	429.73	430.44	431.15	300
310	431.15	431.86	432.56	433.27	433.98	434.69	435.40	436.11	436.82	437.52	438.23	310
320	438.23	438.94	439.65	440.35	441.06	441.76	442.47	443.18	443.88	444.59	445.29	320
330	445.29	446.00	446.70	447.41	448.11	448.81	449.52	450.22	450.93	451.63	452.33	330
340	452.33	453.03	453.74	454.44	455.14	455.84	456.54	457.24	457.95	458.65	459.35	340
350	459.35	460.05	460.75	461.45	462.15	462.85	463.54	464.24	464.94	465.64	466.34	350
360	466.34	467.04	467.73	468.43	469.13	469.83	470.52	471.22	471.92	472.61	473.31	360
370	473.31	474.00	474.70	475.39	476.09	476.78	477.48	478.17	478.87	479.56	480.25	370
380	480.25	480.95	481.64	482.33	483.03	483.72	484.41	485.10	485.79	486.48	487.18	380
390	487.18	487.87	488.56	489.25	489.94	490.63	491.32	492.01	492.70	493.39	494.08	390
400	494.08	494.76	495.45	496.14	496.83	497.52	498.20	498.89	499.58	500.26	500.95	400
410	500.95	501.64	502.32	503.01	503.70	504.38	505.07	505.75	506.44	507.12	507.80	410
420	507.80	508.49	509.17	509.86	510.54	511.22	511.90	512.59	513.27	513.95	514.63	420
430	514.63	515.32	516.00	516.68	517.36	518.04	518.72	519.40	520.08	520.76	521.44	430
440	521.44	522.12	522.80	523.48	524.16	524.83	525.51	526.19	526.87	527.55	528.22	440
450	528.22	528.90	529.58	530.25	530.93	531.61	532.28	532.96	533.63	534.31	534.98	450
460	534.98	535.66	536.33	537.01	537.68	538.36	539.03	539.70	540.38	541.05	541.72	460
470	541.72	542.39	543.07	543.74	544.41	545.08	545.75	546.42	547.09	547.76	548.43	470
480	548.43	549.10	549.77	550.44	551.11	551.78	552.45	553.12	553.79	554.46	555.12	480
490	555.12	555.79	556.46	557.13	557.79	558.46	559.13	559.79	560.46	561.13	561.79	490
500	561.79	562.46	563.12	563.79	564.45	565.12	565.78	566.45	567.11	567.77	568.44	500
510	568.44	569.10	569.76	570.42	571.09	571.75	572.41	573.07	573.73	574.40	575.06	510
520	575.06	575.72	576.38	577.04	577.70	578.36	579.02	579.68	580.34	581.00	581.65	520
530	581.65	582.31	582.97	583.63	584.29	584.94	585.60	586.26	586.92	587.57	588.23	530
540	588.23	588.89	589.54	590.20	590.85	591.51	592.16	592.82	593.47	594.13	594.78	540
550	594.78	595.43	596.09	596.74	597.39	598.05	598.70	599.35	600.00	600.66	601.31	550
560	601.31	601.96	602.61	603.26	603.91	604.56	605.21	605.86	606.51	607.16	607.81	560
570	607.81	608.46	609.11	609.76	610.41	611.06	611.70	612.35	613.00	613.65	614.29	570
580	614.29	614.94	615.59	616.23	616.88	617.53	618.17	618.82	619.46	620.11	620.75	580
590	620.75	621.40	622.04	622.69	623.33	623.97	624.62	625.26	625.90	626.55	627.19	590
600	627.19	627.83	628.47	629.11	629.76	630.40	631.04	631.68	632.32	632.96	633.60	600
610	633.60	634.24	634.88	635.52	636.16	636.80	637.44	638.07	638.71	639.35	639.99	610
620	639.99	640.63	641.26	641.90	642.54	643.17	643.81	644.45	645.08	645.72	646.35	620
630	646.35	646.99	647.62	648.26	648.89	649.53	650.16	650.80	651.43	652.06	652.70	630
640	652.70	653.33	653.96	654.59	655.23	655.86	656.49	657.12	657.75	658.38	659.02	640
650	659.02	659.65	660.28	660.91	661.54	662.17	662.80	663.43	664.05	664.68	665.31	650
660	665.31	665.94	666.57	667.20	667.82	668.45	669.08	669.71	670.33	670.96	671.58	660
670	671.58	672.21	672.84	673.46	674.09	674.71	675.34	675.96	676.59	677.21	677.83	670
680	677.83	678.46	679.08	679.70	680.33	680.95	681.57	682.19	682.82	683.44	684.06	680
690	684.06	684.68	685.30	685.92	686.54	687.16	687.78	688.40	689.02	689.64	690.26	690
700	690.26	690.88	691.50	692.12	692.74	693.36	693.97	694.59	695.21	695.83	696.44	700
710	696.44	697.06	697.68	698.29	698.91	699.52	700.14	700.76	701.37	701.99	702.60	710
720	702.60	703.21	703.83	704.44	705.06	705.67	706.28	706.90	707.51	708.12	708.73	720
730	708.73	709.35	709.96	710.57	711.18	711.79	712.40	713.01	713.62	714.23	714.84	730
740	714.84	715.45	716.06	716.67	717.28	717.89	718.50	719.11	719.72	720.32	720.93	740
750	720.93	721.54	722.15	722.75	723.36	723.97	724.57	725.18	725.78	726.39	726.99	750
760	726.99	727.60	728.20	728.81	729.41	730.02	730.62	731.23	731.83	732.43	733.04	760
770	733.04	733.64	734.24	734.84	735.44	736.05	736.65	737.25	737.85	738.45	739.05	770
780	739.05	739.65	740.25	740.85	741.45	742.05	742.65	743.25	743.85	744.45	745.05	780
790	745.05	745.64	746.24	746.84	747.44	748.04	748.63	749.23	749.83	750.42	751.02	790

Table 8.1.24 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
800	751.02	751.61	752.21	752.80	753.40	753.59	754.59	755.18	755.78	756.37	756.97	800
810	756.97	757.56	758.15	758.75	759.34	759.93	760.52	761.12	761.71	762.30	762.89	810
820	762.89	763.48	764.07	764.66	765.25	765.84	766.43	767.02	767.61	768.20	768.79	820
830	768.79	769.38	769.97	770.56	771.15	771.73	772.32	772.91	773.50	774.08	774.67	830
840	774.67	775.67	775.26	775.84	776.43	777.01	777.60	778.19	778.77	779.94	780.52	840

Platinum 200, Alpha = 0.00385

Resistance as a Function of Temperature (°F)
Reference Standard: IEC 751

Table 8.1.25 Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-330	36.02	36.51	36.99	37.47	37.95	38.43	38.91	39.39	39.87	40.35	40.83	-330
-320	40.83	41.31	41.78	42.26	42.74	43.22	43.70	44.17	44.65	45.13	45.61	-320
-310	45.61	46.08	46.56	47.04	47.51	47.99	48.46	48.94	49.41	49.89	50.36	-310
-300	50.36	50.84	51.31	51.79	52.26	52.74	53.21	53.68	54.16	54.63	55.10	-300
-290	55.10	55.57	56.05	56.52	56.99	57.46	57.93	58.41	58.88	59.35	59.82	-290
-280	59.82	60.29	60.76	61.23	61.70	62.17	62.64	63.11	63.58	64.05	64.52	-280
-270	64.52	64.99	65.45	65.92	66.39	66.86	67.33	67.79	68.26	68.73	69.20	-270
-260	69.20	69.66	70.13	70.60	71.06	71.53	71.99	72.46	72.93	73.39	73.86	-260
-250	73.86	74.32	74.79	75.25	75.72	76.18	76.65	77.11	77.57	78.04	78.50	-250
-240	78.50	78.96	79.43	79.89	80.35	80.82	81.28	81.74	82.20	82.67	83.13	-240
-230	83.13	83.59	84.05	84.51	84.97	85.43	85.90	86.36	86.82	87.28	87.74	-230
-220	87.74	88.20	88.66	89.12	89.58	90.04	90.50	90.96	91.42	91.87	92.33	-220
-210	92.33	92.79	93.25	93.71	94.17	94.63	95.08	95.54	96.00	96.46	96.91	-210
-200	96.91	97.37	97.83	98.28	98.74	99.20	99.65	100.11	100.57	101.02	101.48	-200
-190	101.48	101.93	102.39	102.85	103.30	103.76	104.21	104.67	105.12	105.58	106.03	-190
-180	106.03	106.49	106.94	107.39	107.85	108.30	108.76	109.21	109.66	110.12	110.57	-180
-170	110.57	111.02	111.48	111.93	112.38	112.83	113.29	113.74	114.19	114.64	115.09	-170
-160	115.09	115.55	116.00	116.45	116.90	117.35	117.80	118.25	118.71	119.16	119.61	-160
-150	119.61	120.06	120.51	120.96	121.41	121.86	122.31	122.76	123.21	123.66	124.11	-150
-140	124.11	124.56	125.01	125.46	125.91	126.35	126.80	127.25	127.70	128.15	128.60	-140
-130	128.60	129.05	129.49	129.94	130.39	130.84	131.29	131.73	132.18	132.63	133.08	-130
-120	133.08	133.52	133.97	134.42	134.86	135.31	135.76	136.20	136.65	137.10	137.54	-120
-110	137.54	137.99	138.44	138.88	139.33	139.77	140.22	140.66	141.11	141.55	142.00	-110
-100	142.00	142.45	142.89	143.34	143.78	144.22	144.67	145.11	145.56	146.00	146.45	-100
-90	146.45	146.89	147.34	147.78	148.22	148.67	149.11	149.55	150.00	150.44	150.88	-90
-80	150.88	151.33	151.77	152.21	152.66	153.10	153.54	153.98	154.45	154.87	155.31	-80
-70	155.31	155.75	156.20	156.64	157.08	157.52	157.96	158.41	158.85	159.29	159.73	-70
-60	159.73	160.17	160.61	161.05	161.50	161.94	162.38	162.82	163.26	163.70	164.14	-60
-50	164.14	164.58	165.02	165.46	165.90	166.34	166.78	167.22	167.66	168.10	168.54	-50
-40	168.54	168.98	169.42	169.86	170.30	170.74	171.18	171.62	172.06	172.50	172.94	-40
-30	172.94	173.37	173.81	174.25	174.69	175.13	175.57	176.01	176.44	176.88	177.32	-30
-20	177.32	177.76	178.20	178.63	179.07	179.51	179.95	180.39	180.82	181.26	181.70	-20
-10	181.70	182.14	182.57	183.01	183.45	183.88	184.32	184.76	185.19	185.63	186.07	-10
0	186.07	186.50	186.94	187.38	187.81	188.25	188.69	189.12	189.56	189.99	190.43	0
10	190.43	190.87	191.30	191.74	192.17	192.61	193.04	193.48	193.91	194.35	194.78	10
20	194.78	195.22	195.65	196.09	196.52	196.96	197.39	197.83	198.26	198.70	199.13	20
30	199.13	199.57	200.00	200.43	200.87	201.30	201.74	202.17	202.60	203.04	203.47	30
40	203.47	203.91	204.34	204.77	205.21	205.64	206.07	206.51	206.94	207.37	207.80	40

Table 8.1.25 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
50	207.80	208.24	208.67	209.10	209.54	209.97	210.40	210.83	211.27	211.70	212.13	50
60	212.13	212.56	212.99	213.43	213.86	214.29	214.72	215.15	215.59	216.02	216.45	60
70	216.45	216.88	217.31	217.74	218.17	218.61	219.04	219.47	219.90	220.33	220.76	70
80	220.76	221.19	221.62	222.05	222.48	222.91	223.34	223.77	224.20	224.63	225.06	80
90	225.06	225.49	225.92	226.35	226.78	227.21	227.64	228.07	228.50	228.93	229.36	90
100	229.36	229.79	230.22	230.65	231.08	231.51	231.94	232.37	232.79	233.22	233.65	100
110	233.65	234.08	234.51	234.94	235.37	235.79	236.22	236.65	237.08	237.51	237.93	110
120	237.93	238.36	238.79	239.22	239.65	240.07	240.50	240.93	241.36	241.78	242.21	120
130	242.21	242.64	243.06	243.49	243.92	244.35	244.77	245.20	245.63	246.05	246.48	130
140	246.48	246.90	247.33	247.76	248.18	248.61	249.04	249.46	249.89	250.31	250.74	140
150	250.74	251.17	251.59	252.02	252.44	252.87	253.29	253.72	254.14	254.57	254.99	150
160	254.99	255.42	255.84	256.27	256.69	257.12	257.54	257.97	258.39	258.82	259.24	160
170	259.24	259.67	260.09	260.51	260.94	261.36	261.79	262.21	262.63	263.06	263.48	170
180	263.48	263.90	264.33	264.75	265.17	265.60	266.02	266.44	266.87	267.29	267.71	180
190	267.71	268.14	268.56	268.98	269.40	269.83	270.25	270.67	271.09	271.52	271.94	190
200	271.94	272.36	272.78	273.21	273.63	274.05	274.47	274.89	275.31	275.74	276.16	200
210	276.16	276.58	277.00	277.42	277.84	278.26	278.68	279.11	279.53	279.95	280.37	210
220	280.37	280.79	281.21	281.63	282.05	282.47	282.89	283.31	283.73	284.15	284.57	220
230	284.57	284.99	285.41	285.83	286.25	286.67	287.09	287.51	287.93	288.35	288.77	230
240	288.77	289.19	289.61	290.03	290.45	290.86	291.28	291.70	292.12	292.54	292.96	240
250	292.96	293.38	293.80	294.21	294.63	295.05	295.47	295.89	296.31	296.72	297.14	250
260	297.14	297.56	297.98	298.39	298.81	299.23	299.65	300.06	300.48	300.90	301.32	260
270	301.32	301.73	302.15	302.57	302.98	303.40	303.82	304.24	304.65	305.07	305.48	270
280	305.48	305.90	306.32	306.73	307.15	307.57	307.98	308.40	308.81	309.23	309.65	280
290	309.65	310.06	310.48	310.89	311.31	311.72	312.14	312.55	312.97	313.38	313.80	290
300	313.80	314.21	314.63	315.04	315.46	315.87	316.29	316.70	317.12	317.53	317.95	300
310	317.95	318.36	318.77	319.19	319.60	320.02	320.43	320.84	321.26	321.67	322.09	310
320	322.09	322.50	322.91	323.33	323.74	324.15	324.57	324.98	325.39	325.81	326.22	320
330	326.22	326.63	327.04	327.46	327.87	328.28	328.69	329.11	329.52	329.93	330.34	330
340	330.34	330.76	331.17	331.58	331.99	332.40	332.82	333.23	333.64	334.05	334.46	340
350	334.46	334.87	335.28	335.70	336.11	336.52	336.93	337.34	337.75	338.16	338.57	350
360	338.57	338.98	339.39	339.80	340.21	340.63	341.04	341.45	341.86	342.27	342.68	360
370	342.68	343.09	343.50	343.91	344.32	344.73	345.14	345.54	345.95	346.36	346.77	370
380	346.77	347.18	347.59	348.00	348.41	348.82	349.23	349.64	350.04	350.45	350.86	380
390	350.86	351.27	351.68	352.09	352.50	352.90	353.31	353.72	354.13	354.54	354.94	390
400	354.94	355.35	355.76	356.17	356.58	356.98	357.39	357.80	358.21	358.61	359.02	400
410	359.02	359.43	359.83	360.24	360.65	361.05	361.46	361.87	362.27	362.68	363.09	410
420	363.09	363.49	363.90	364.31	364.71	365.12	365.52	365.93	366.34	366.74	367.15	420
430	367.15	367.55	367.96	368.36	368.77	369.18	369.58	369.99	370.39	370.80	371.20	430
440	371.20	371.61	372.01	372.42	372.82	373.23	373.63	374.03	374.44	374.84	375.25	440
450	375.25	375.65	376.06	376.46	376.86	377.27	377.67	378.08	378.48	378.88	379.29	450
460	379.29	379.69	380.09	380.50	380.90	381.30	381.71	382.11	382.51	382.92	383.32	460
470	383.32	383.72	384.13	384.53	384.93	385.33	385.74	386.14	386.54	386.94	387.34	470
480	387.34	387.75	388.15	388.55	388.95	389.35	389.76	390.16	390.56	390.96	391.36	480
490	391.36	391.76	392.16	392.57	392.97	393.37	393.77	394.17	394.57	394.97	395.37	490
500	395.37	395.77	396.17	396.57	396.97	397.38	397.78	398.18	398.58	398.98	399.38	500
510	399.38	399.78	400.18	400.58	400.98	401.38	401.77	402.17	402.57	402.97	403.37	510
520	403.37	403.77	404.17	404.57	404.97	405.37	405.77	406.17	406.56	406.96	407.36	520
530	407.36	407.76	408.16	408.56	408.96	409.35	409.75	410.15	410.55	410.95	411.34	530
540	411.34	411.74	412.14	412.54	412.93	413.33	413.73	414.13	414.52	414.92	415.32	540
550	415.32	415.72	416.11	416.51	416.91	417.30	417.70	418.10	418.49	418.89	419.29	550
560	419.29	419.68	420.08	420.47	420.87	421.27	421.66	422.06	422.45	422.85	423.25	560
570	423.25	423.64	424.04	424.43	424.83	425.22	425.62	426.01	426.41	426.80	427.20	570

Table 8.1.25 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
580	427.20	427.59	427.99	428.38	428.78	429.17	429.57	429.96	430.36	430.75	431.15	580
590	431.15	431.54	431.93	432.33	432.72	433.12	433.51	433.90	434.30	434.69	435.08	590
600	435.08	435.48	435.87	436.27	436.66	437.05	437.44	437.84	438.23	438.62	439.02	600
610	439.02	439.41	439.80	440.19	440.59	440.98	441.37	441.76	442.16	442.55	442.94	610
620	442.94	443.33	443.73	444.12	444351	444.90	445.29	445.68	446.08	446.47	446.86	620
630	446.86	447.25	447.64	448.03	448.42	448.81	449.21	449.60	449.99	450.38	450.77	630
640	450.77	451.16	451.55	451.94	452.33	456.72	453.11	453.50	453.89	454.28	454.67	640
650	454.67	455.06	455.45	455.84	456.23	456.62	457.01	457.40	457.79	458.18	458.57	650
660	458.57	458.96	459.35	459.74	460.12	460.51	460.90	461.29	461.68	462.07	462.46	660
670	462.46	462.85	463.23	463.62	464.01	464.40	464.79	465.17	465.56	465.95	466.34	670
680	466.34	466.73	467.11	467.50	467.89	468.28	468.66	469.05	469.44	469.83	470.21	680
690	470.21	470.60	470.99	471.37	417.76	472.15	472.53	472.92	473.31	473.69	474.08	690
700	474.08	474.47	474.85	485.24	475.63	476.01	476.40	476.78	477.17	477.56	477.94	700
710	477.94	478.33	478.71	479.10	479.48	479.87	480.25	480.64	481.02	481.41	481.79	710
720	481.79	482.18	482.56	482.95	483.33	483.72	484.10	484.49	484.87	485.26	485.64	720
730	485.64	486.02	486.41	486.79	487.18	487.56	487.94	488.33	488.71	489.09	489.48	730
740	489.48	489.86	490.25	490.63	491.01	491.39	491.78	492.16	492.54	492.93	493.31	740
750	493.31	493.69	494.08	494.46	494.84	495.22	495.61	495.99	496.37	496.75	497.13	750
760	497.13	497.52	497.90	498.28	498.66	499.04	499.43	499.81	500.19	500.57	500.95	760
770	500.95	501.33	501.71	502.10	502.48	502.86	503.24	503.62	504.00	504.38	504.76	770
780	504.76	505.14	505.52	505.90	506.28	506.66	507.04	507.42	507.80	508.18	508.56	780
790	508.56	508.94	509.32	509.70	510.08	510.46	510.84	511.22	511.60	511.98	512.36	790
800	512.36	512.74	513.12	513.50	513.88	514.26	514.63	515.01	515.39	515.77	516.15	800
810	516.15	516.53	516.91	517.28	517.66	518.04	518.42	518.80	519.17	519.55	519.93	810
820	519.93	520.31	520.69	521.06	521.44	521.82	522.20	522.57	522.95	523.33	523.70	820
830	523.70	524.08	524.46	524.83	525.21	525.59	525.97	526.34	526.72	527.09	527.47	830
840	527.47	527.85	528.22	528.60	528.98	529.35	529.73	530.10	530.48	530.86	531.23	840
850	531.23	531.61	531.98	532.36	532.73	533.11	533.48	533.86	534.23	534.61	534.98	850
860	534.98	535.36	535.73	536.11	536.48	536.86	537.23	537.61	537.98	538.36	538.73	860
870	538.73	539.10	539.48	539.85	540.23	540.60	540.97	541.35	541.72	542.09	542.47	870
880	542.47	542.84	543.21	543.59	543.96	544.33	544.71	545.08	545.45	545.83	546.20	880
890	546.20	546.57	546.94	547.32	547.69	548.06	548.43	548.81	549.18	549.55	549.92	890
900	549.92	550.30	550.67	551.04	551.41	551.78	552.15	552.53	552.90	553.27	553.64	900
910	553.64	554.01	554.38	554.75	555.12	555.50	555.87	556.24	556.61	556.98	557.35	910
920	557.35	557.72	558.09	558.46	558.83	559.20	559.57	559.94	560.31	560.68	561.05	920
930	561.05	561.42	561.79	562.16	562.53	562.90	563.27	563.64	564.01	564.38	564.75	930
940	564.75	565.12	565.49	565.86	566.22	566.59	566.96	567.33	567.70	568.07	568.44	940
950	568.44	568.80	569.17	569.54	569.91	570.28	570.65	571.01	571.38	571.75	572.12	950
960	572.12	572.48	572.85	573.22	573.59	573.96	574.32	574.69	575.06	575.42	575.79	960
970	575.79	576.16	576.53	576.89	577.26	577.63	577.99	578.36	578.73	579.09	579.46	970
980	579.46	579.82	580.19	580.56	580.92	581.29	581.65	582.02	582.39	582.75	583.12	980
990	583.12	583.48	583.85	584.21	584.58	584.94	585.31	585.67	586.04	586.41	586.77	990
1000	586.77	587.13	587.50	587.86	588.23	588.59	588.96	589.32	589.69	590.05	590.42	1000
1010	590.42	590.78	591.14	591.51	591.87	592.24	592.60	592.96	593.33	593.69	594.05	1010
1020	594.05	594.42	594.78	595.14	595.51	595.87	596.23	596.60	596.96	597.32	597.68	1020
1030	597.68	598.05	598.41	598.77	599.13	599.50	599.86	600.22	600.58	600.95	601.31	1030
1040	601.31	601.67	602.03	602.39	602.76	603.12	603.48	603.84	604.20	604.56	604.92	1040
1050	604.92	605.29	605.65	606.01	606.37	606.73	607.09	607.45	607.81	608.17	608.53	1050
1060	608.53	608.89	609.26	609.62	609.98	610.34	610.70	611.06	611.42	611.78	612.14	1060
1070	612.14	612.50	612.86	613.22	613.58	613.94	614.29	614.65	615.01	615.37	615.73	1070
1080	615.73	616.09	616.45	616.81	617.17	617.53	617.89	618.24	618.60	618.96	619.32	1080
1090	619.32	619.68	620.04	620.39	620.75	621.11	621.47	621.83	622.18	622.54	622.90	1090
1100	622.90	623.26	623.62	623.97	624.33	624.69	625.05	625.40	625.76	626.12	626.47	1100

Table 8.1.25 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1110	626.47	626.83	627.19	627.54	627.90	628.26	628.61	628.97	629.33	629.68	630.04	1110
1120	630.04	630.40	630.75	631.11	631.47	631.82	632.18	632.53	632.89	633.24	633.60	1120
1130	633.60	633.96	634.31	634.67	635.02	635.38	635.73	636.09	636.44	636.80	637.15	1130
1140	637.15	637.51	637.86	638.22	638.57	638.93	639.28	639.63	639.99	640.34	640.70	1140
1150	640.70	641.05	641.41	641.76	642.11	642.47	642.82	643.17	643.53	643.88	644.24	1150
1160	644.24	644.59	644.94	645.30	645.65	646.00	646.35	646.71	647.06	647.41	647.77	1160
1170	647.77	648.12	648.47	648.82	649.18	649.53	649.88	650.23	650.59	650.94	651.29	1170
1180	651.29	651.64	651.99	652.34	652.70	653.05	653.40	653.75	654.10	654.45	654.81	1180
1190	654.81	655.16	655.51	655.86	656.21	656.56	656.91	657.26	657.61	657.96	658.31	1190
1200	658.31	658.67	659.02	659.37	659.72	660.07	660.42	660.77	661.12	661.47	661.82	1200
1210	661.82	662.17	662.52	662.87	663.22	663.57	663.91	664.26	664.61	664.96	665.31	1210
1220	665.31	665.66	666.01	666.36	666.71	667.06	667.41	667.75	668.10	668.45	668.80	1220
1230	668.80	669.15	669.50	669.84	670.19	670.54	670.89	671.24	671.58	671.93	672.28	1230
1240	672.28	672.63	672.98	673.32	673.67	674.02	674.36	674.71	675.06	675.41	675.75	1240
1250	675.75	676.10	676.45	676.79	677.14	677.49	677.83	678.18	678.53	678.87	679.22	1250
1260	679.22	679.57	679.91	680.26	680.60	680.95	681.30	681.64	681.99	682.33	682.68	1260
1270	682.68	683.02	683.37	683.71	684.06	684.41	684.75	685.10	685.44	685.79	686.13	1270
1280	686.13	686.48	686.82	687.16	687.51	687.85	688.20	688.54	688.89	689.23	689.58	1280
1290	689.58	689.92	690.26	690.61	690.95	691.29	691.64	691.98	692.33	692.67	693.01	1290
1300	693.01	693.36	693.70	694.04	694.39	694.73	695.07	695.41	695.76	696.10	696.44	1300
1310	696.44	696.79	697.13	697.47	697.81	698.16	698.50	698.84	699.18	699.52	699.87	1310
1320	699.87	700.21	700.55	700.89	701.23	701.58	701.92	702.26	702.60	702.94	703.28	1320
1330	703.28	703.62	703.96	704.31	704.65	704.99	705.33	705.67	706.01	706.35	706.69	1330
1340	706.69	707.03	707.37	707.71	708.05	708.39	708.73	709.07	709.41	709.75	710.09	1340
1350	710.09	710.43	710.77	711.11	711.45	711.79	712.13	712.47	712.81	713.15	713.49	1350
1360	713.49	713.83	714.17	714.50	714.84	715.18	715.52	715.86	716.20	716.54	716.88	1360
1370	716.88	717.21	717.55	717.89	718.23	718.57	718.90	719.24	719.58	719.92	720.26	1370
1380	720.26	720.59	720.93	721.27	721.61	721.94	722.28	722.62	722.95	723.29	723.63	1380
1390	723.63	723.97	724.30	724.64	724.98	725.31	725.65	725.99	726.32	726.66	726.99	1390
1400	726.99	727.33	727.67	728.00	728.34	728.67	729.01	729.35	729.68	730.02	730.35	1400
1410	730.35	730.69	731.02	731.36	731.69	732.03	732.37	732.70	733.04	733.37	733.70	1410
1420	733.70	734.04	734.37	734.71	735.04	735.38	735.71	736.05	736.38	736.72	737.05	1420
1430	737.05	737.38	737.72	738.05	738.39	738.72	739.05	739.39	739.72	740.05	740.39	1430
1440	740.39	740.72	741.05	741.39	741.72	742.05	742.39	742.72	743.05	743.38	743.72	1440
1450	743.72	744.05	744.38	744.71	745.05	745.38	745.71	746.04	746.38	746.71	747.04	1450
1460	747.04	747.37	747.70	748.04	748.37	748.70	749.03	749.36	749.69	750.02	750.36	1460
1470	750.36	750.69	751.02	751.35	751.68	752.01	752.34	752.67	753.00	753.33	753.66	1470
1480	753.66	753.99	754.32	754.66	754.99	755.32	755.65	755.98	756.31	756.64	756.97	1480
1490	756.97	757.30	757.62	757.95	758.28	758.61	758.94	759.27	759.60	759.93	760.26	1490
1500	760.26	760.59	760.92	761.25	761.58	761.90	762.23	762.56	762.89	763.22	763.55	1500
1510	763.55	763.88	764.20	764.53	764.86	765.19	765.52	765.84	766.17	766.50	766.83	1501
1520	766.83	767.15	767.48	767.81	768.14	768.46	768.79	769.12	769.45	769.77	770.10	1520
1530	770.10	770.43	770.75	771.08	771.41	771.73	772.06	772.39	772.71	773.04	773.37	1530
1540	773.37	773.69	774.02	774.34	774.67	775.00	775.32	775.65	775.97	776.30	776.62	1540
1550	776.62	776.95	777.27	777.60	777.93	778.25	778.58	778.90	779.23	779.55	779.88	1550
1560	779.88	780.20	780.52									1560

Platinum 500, Alpha = 0.00385

Resistance as a Function of Temperature (°C)
Reference Standard: IEC 751

Table 8.1.26 Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-200	92.47	94.63	96.79	98.95	101.11	103.26	105.42	107.57	109.72	111.87	114.02	-200
-190	114.02	116.16	118.30	120.45	122.59	124.72	126.86	129.00	131.13	133.26	135.39	-190
-180	135.39	137.52	139.64	141.77	143.89	146.01	148.13	150.25	152.37	154.49	156.60	-180
-170	156.60	158.71	160.82	162.93	165.04	167.15	169.25	171.35	173.46	175.56	177.66	-170
-160	177.66	179.75	181.85	183.94	186.04	188.13	190.22	192.31	194.40	196.48	198.57	-160
-150	198.57	200.65	202.73	204.82	206.89	208.97	211.05	213.13	215.20	217.27	219.35	-150
-140	219.35	221.42	223.49	225.55	227.62	229.69	231.75	233.81	235.88	237.94	240.00	-140
-130	240.00	242.05	244.11	246.17	248.22	250.28	252.33	254.38	256.43	258.48	260.53	-130
-120	260.53	262.58	264.62	266.67	268.71	270.75	272.80	274.84	276.88	278.91	280.95	-120
-110	280.95	282.99	285.02	287.06	289.09	291.12	293.15	295.19	297.21	299.24	301.27	-110
-100	301.27	303.30	305.32	307.35	309.37	311.39	313.42	315.44	317.46	319.48	321.49	-100
-90	321.49	323.51	325.53	327.54	329.56	331.57	333.58	335.60	337.61	339.62	341.63	-90
-80	341.63	343.63	345.64	347.65	349.65	351.66	353.66	355.67	357.67	359.67	361.67	-80
-70	361.67	363.67	365.67	367.67	369.67	371.67	373.66	375.66	377.65	379.65	381.64	-70
-60	381.64	383.63	385.63	387.62	389.61	391.60	393.59	395.57	397.56	399.55	401.53	-60
-50	401.53	403.52	405.50	407.49	409.47	411.45	413.44	415.42	417.40	419.38	421.36	-50
-40	421.36	423.33	425.31	427.29	429.27	431.24	433.22	435.19	437.17	439.14	441.11	-40
-30	441.11	443.08	445.05	447.02	448.99	450.96	452.93	454.90	456.87	458.84	460.80	-30
-20	460.80	462.77	464.73	466.70	468.66	470.62	472.59	474.55	476.51	478.47	480.43	-20
-10	480.43	482.39	484.35	486.31	488.27	490.22	492.18	494.14	496.09	498.05	500.00	-10
0	500.00	501.95	503.91	505.86	507.81	509.76	511.71	513.66	515.61	517.56	519.51	0
10	519.51	521.46	523.41	525.35	527.30	529.24	531.19	533.13	535.08	537.02	538.96	10
20	538.96	540.91	542.85	544.79	546.73	548.67	550.61	552.55	554.48	556.42	558.36	20
30	558.36	560.30	562.23	564.17	566.10	568.03	569.97	571.90	573.83	575.77	577.70	30
40	577.70	579.63	581.56	583.49	585.41	587.34	589.27	591.20	593.12	595.05	596.98	40
50	596.98	598.90	600.82	602.75	604.67	606.59	608.51	610.44	612.36	614.28	616.20	50
60	616.20	618.12	620.03	621.95	623.87	625.78	627.70	629.62	631.53	633.45	635.36	60
70	635.36	637.27	639.18	641.10	643.01	644.92	646.83	648.74	650.65	652.56	654.46	70
80	654.46	656.37	658.28	660.18	662.09	663.99	665.90	667.80	669.71	671.61	673.51	80
90	673.51	675.41	677.31	679.21	681.11	683.01	684.91	686.81	688.71	690.60	692.50	90
100	692.50	694.40	696.29	698.19	700.08	701.97	703.87	705.76	707.65	709.54	711.43	100
110	711.43	713.32	715.21	717.10	718.99	720.87	722.76	724.65	726.53	728.42	730.30	110
120	730.30	732.19	734.07	735.95	737.84	739.72	741.60	743.48	745.36	747.24	749.12	120
130	749.12	751.00	752.87	754.75	756.63	758.50	760.38	762.25	764.13	766.00	767.88	130
140	767.88	769.75	771.62	773.49	775.36	777.23	779.10	780.97	782.84	784.71	786.57	140
150	786.57	788.44	790.31	792.17	794.04	795.90	797.77	799.63	801.49	803.35	805.22	150
160	805.22	807.08	808.94	810.80	812.66	814.51	816.37	818.23	820.09	821.94	823.80	160
170	823.80	825.65	827.51	829.36	831.21	833.07	834.92	836.77	838.62	840.47	842.32	170
180	842.32	844.17	846.02	847.87	849.72	851.56	853.41	855.26	857.10	858.95	860.79	180
190	860.79	862.63	864.48	866.32	868.16	870.00	871.84	873.68	875.52	877.36	879.20	190
200	879.20	881.04	882.87	884.71	886.55	888.38	890.22	892.05	893.88	895.72	897.55	200
210	897.55	899.38	901.21	903.04	904.87	906.70	908.53	910.36	912.19	914.01	915.84	210
220	915.84	917.67	919.49	921.32	923.14	924.97	926.79	928.61	930.43	932.26	934.08	220
230	934.08	935.90	937.72	939.54	941.35	943.17	944.99	946.81	948.62	950.44	952.25	230
240	952.25	954.07	955.88	957.69	959.51	961.32	963.13	964.94	966.75	968.56	970.37	240
250	970.37	972.18	973.99	975.80	977.60	979.41	981.21	983.02	984.82	986.63	988.43	250
260	988.43	990.23	992.04	993.84	995.64	997.44	999.24	1001.04	1002.84	1004.64	1006.43	260

Table 8.1.26 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
270	1006.43	1008.23	1010.03	1011.82	1013.62	1015.41	1017.21	1019.00	1020.79	1022.59	1024.38	270
280	1024.38	1026.17	1027.96	1029.75	1031.54	1033.33	1035.12	1036.91	1038.69	1040.48	1042.27	280
290	1042.27	1044.05	1045.84	1047.62	1049.40	1051.19	1052.97	1054.75	1056.53	1058.31	1060.09	290
300	1060.09	1061.87	1063.65	1065.43	1067.21	1068.99	1070.76	1072.54	1074.32	1076.09	1077.86	300
310	1077.86	1079.64	1081.41	1083.18	1084.96	1086.73	1088.50	1090.27	1092.04	1093.81	1095.58	310
320	1095.58	1097.35	1099.11	1100.88	1102.65	1104.41	1106.18	1107.94	1109.71	1111.47	1113.23	320
330	1113.23	1114.99	1116.76	1118.52	1120.28	1122.04	1123.80	1125.56	1127.31	1129.07	1130.83	330
340	1130.83	1132.58	1134.34	1136.10	1137.85	1139.60	1141.36	1143.11	1144.86	1146.62	1148.37	340
350	1148.37	1150.12	1151.87	1153.62	1155.37	1157.11	1158.86	1160.61	1162.36	1164.10	1165.85	350
360	1165.85	1167.59	1169.34	1171.08	1172.82	1174.57	1176.31	1178.05	1179.79	1181.53	1183.27	360
370	1183.27	1185.01	1186.75	1188.48	1190.22	1191.96	1193.69	1195.43	1197.17	1198.90	1200.63	370
380	1200.63	1202.37	1204.10	1205.83	1207.56	1209.29	1211.02	1212.75	1214.48	1216.21	1217.94	380
390	1217.94	1219.67	1221.39	1223.12	1224.85	1226.57	1228.30	1230.02	1231.74	1233.47	1235.19	390
400	1235.19	1236.91	1238.63	1240.35	1242.07	1243.79	1245.51	1247.23	1248.94	1250.66	1252.38	400
410	1252.38	1254.09	1255.81	1257.52	1259.24	1260.95	1262.66	1264.38	1266.09	1267.80	1269.51	410
420	1269.51	1271.22	1272.93	1274.64	1276.35	1278.06	1279.76	1281.47	1283.17	1284.88	1286.58	420
430	1286.58	1288.29	1289.99	1291.70	1293.40	1295.10	1296.80	1298.50	1300.20	1301.90	1303.60	430
440	1303.60	1305.30	1307.00	1308.69	1310.39	1312.09	1313.78	1315.48	1317.17	1318.87	1320.56	440
450	1320.56	1322.25	1323.94	1325.64	1327.33	1329.02	1330.71	1332.40	1334.08	1335.77	1337.46	450
460	1337.46	1339.15	1340.83	1342.52	1344.20	1345.89	1347.57	1349.26	1350.94	1352.62	1354.30	460
470	1354.30	1355.98	1357.66	1359.34	1361.02	1362.70	1364.38	1366.06	1367.73	1369.41	1371.09	470
480	1371.09	1372.76	1374.44	1376.11	1377.78	1379.46	1381.13	1382.80	1384.47	1386.14	1387.81	480
490	1387.81	1389.48	1391.15	1392.82	1394.49	1396.15	1397.82	1399.49	1401.15	1402.82	1404.48	490
500	1404.48	1406.14	1407.81	1409.47	1411.13	1412.79	1414.45	1416.11	1417.77	1419.43	1421.09	500
510	1421.09	1422.75	1424.41	1426.06	1427.72	1429.37	1431.03	1432.68	1434.34	1435.99	1437.64	510
520	1437.64	1439.29	1440.95	1442.60	1444.25	1445.90	1447.55	1449.19	1450.84	1452.49	1454.14	520
530	1454.14	1455.78	1457.43	1459.07	1460.72	1462.36	1464.00	1465.65	1467.29	1468.93	1470.57	530
540	1470.57	1472.21	1473.85	1475.49	1477.13	1478.77	1480.41	1482.04	1483.68	1485.32	1486.95	540
550	1486.95	1488.59	1490.22	1491.85	1493.49	1495.12	1496.75	1498.38	1500.01	1501.64	1503.27	550
560	1503.27	1504.90	1506.53	1508.16	1509.78	1511.41	1513.03	1514.66	1516.28	1517.91	1519.53	560
570	1519.53	1521.16	1522.78	1524.40	1526.02	1527.64	1529.26	1530.88	1532.50	1534.12	1535.74	570
580	1535.74	1537.35	1538.97	1540.59	1542.20	1543.82	1545.43	1547.04	1548.66	1550.27	1551.88	580
590	1551.88	1553.49	1555.10	1556.71	1558.32	1559.93	1561.54	1563.15	1564.76	1566.36	1567.97	590
600	1567.97	1569.58	1571.18	1572.79	1574.39	1575.99	1577.60	1579.20	1580.80	1582.40	1584.00	600
610	1584.00	1585.60	1587.20	1588.80	1590.40	1591.99	1593.59	1595.19	1596.78	1598.38	1599.97	610
620	1599.97	1601.57	1603.16	1604.75	1606.34	1607.94	1609.53	1611.12	1612.71	1614.30	1615.89	620
630	1615.89	1617.47	1619.06	1620.65	1622.24	1623.82	1625.41	1626.99	1628.58	1630.16	1631.74	630
640	1631.74	1633.32	1634.91	1636.49	1638.07	1639.65	1641.23	1642.81	1644.38	1645.96	1647.54	640
650	1647.54	1649.12	1650.69	1652.27	1653.84	1655.42	1656.99	1658.56	1660.14	1661.71	1663.28	650
660	1663.28	1664.85	1666.42	1667.99	1669.56	1671.13	1672.70	1674.26	1675.83	1677.40	1678.96	660
670	1678.96	1680.53	1682.09	1683.65	1685.22	1686.78	1688.34	1689.90	1691.46	1693.03	1694.58	670
680	1694.58	1696.14	1697.70	1699.26	1700.82	1702.37	1703.93	1705.49	1707.04	1708.60	1710.15	680
690	1710.15	1711.70	1713.26	1714.81	1716.36	1717.91	1719.46	1721.01	1722.56	1724.11	1725.66	690
700	1725.66	1727.21	1728.75	1730.30	1731.85	1733.39	1734.94	1736.48	1738.02	1739.57	1741.11	700
710	1741.11	1742.65	1744.19	1756.73	1747.27	1748.81	1750.35	1751.89	1753.43	1754.96	1756.50	710
720	1756.50	1758.04	1759.57	1761.11	1762.64	1764.17	1765.71	1767.24	1768.77	1770.30	1771.83	720
730	1771.83	1773.36	1774.89	1776.42	1777.95	1779.48	1781.01	1782.53	1784.06	1785.58	1787.11	730
740	1787.11	1788.63	1790.16	1791.68	1793.20	1794.72	1796.25	1797.77	1799.29	1800.81	1802.33	740
750	1802.33	1803.85	1805.36	1806.99	1808.40	1809.91	1811.43	1812.94	1841.46	1815.97	1817.49	750
760	1817.49	1819.00	1820.51	1822.02	1823.53	1825.04	1826.55	1828.06	1829.57	1831.08	1832.59	760
770	1832.59	1834.09	1835.60	1837.11	1838.61	1840.12	1841.62	1843.12	1844.63	1846.13	1847.63	770
780	1847.63	1849.13	1850.63	1852.13	1853.63	1855.13	1856.63	1858.13	1859.62	1861.12	1862.62	780
790	1862.62	1864.11	1865.61	1867.10	1868.59	1870.09	1871.58	1873.07	1874.56	1876.05	1877.54	790

Table 8.1.26 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
800	1877.54	1879.03	1880.52	1882.01	1883.50	1884.99	1886.47	1887.96	1889.44	1890.93	1892.41	800
810	1892.41	1893.90	1895.38	1896.86	1898.35	1899.83	1901.31	1902.79	1904.27	1905.75	1907.23	810
820	1907.23	1908.70	1910.18	1911.66	1913.13	1914.61	1916.08	1917.56	1919.03	1920.51	1921.98	820
830	1921.98	1923.45	1924.92	1926.39	1927.86	1929.33	1930.80	1932.27	1933.74	1935.21	1936.67	830
840	1936.67	1938.14	1939.61	1941.07	1942.54	1944.00	1945.46	1946.93	1948.39	1949.85	1951.31	840

Platinum 500, Alpha = 0.00385

Resistance as a Function of Temperature (°F)
Reference Standard: IEC 751

Table 8.1.27 Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-330	90.06	91.26	92.47	93.67	94.87	96.07	97.27	98.47	99.67	100.87	102.07	-330
-320	102.07	103.26	104.46	105.66	106.85	108.05	109.24	110.44	111.63	112.82	114.02	-320
-310	114.02	115.21	116.40	117.59	118.78	119.97	121.16	122.35	123.54	124.72	125.91	-310
-300	125.91	127.10	128.28	129.47	130.65	131.84	133.02	134.21	135.39	136.57	137.75	-300
-290	137.75	138.94	140.12	141.30	142.48	143.66	144.84	146.01	147.19	148.37	149.55	-290
-280	149.55	150.72	151.90	153.08	154.25	155.43	156.60	157.77	158.95	160.12	161.29	-280
-270	161.29	162.46	163.64	164.81	165.98	167.15	167.32	169.49	170.65	171.82	172.99	-270
-260	172.99	174.16	175.32	176.49	177.66	178.82	179.99	181.15	182.32	183.48	184.64	-260
-250	184.64	185.81	186.97	188.13	189.29	190.45	191.61	192.77	193.93	195.09	196.25	-250
-240	196.25	197.41	198.57	199.73	200.88	202.04	203.20	204.35	205.51	206.66	207.82	-240
-230	207.82	208.97	210.13	211.28	212.43	213.59	214.74	215.89	217.04	218.19	219.35	-230
-220	219.35	220.50	221.65	222.80	223.95	225.09	226.24	227.39	228.54	229.69	230.83	-220
-210	230.83	231.98	233.13	234.27	235.42	236.56	237.71	238.85	240.00	241.14	242.28	-210
-200	242.28	243.43	244.57	245.71	246.85	247.99	249.14	250.28	251.42	252.56	253.70	-200
-190	253.70	254.84	255.98	257.11	258.25	259.39	260.53	261.67	262.80	263.94	265.08	-190
-180	265.08	266.21	267.35	268.48	269.62	270.75	271.89	273.02	274.16	275.29	276.42	-180
-170	276.42	277.56	278.69	279.82	280.95	282.08	283.21	284.34	285.48	286.61	287.74	-170
-160	287.74	288.87	289.99	291.12	292.25	293.38	294.51	295.64	296.76	297.89	299.02	-160
-150	299.02	300.14	301.27	302.40	303.52	304.65	305.77	306.90	308.02	309.15	310.27	-150
-140	310.27	311.39	312.52	313.64	314.76	315.89	317.01	318.13	319.25	320.37	321.49	-140
-130	321.49	322.61	323.73	324.85	325.97	327.09	328.21	329.33	330.45	331.57	332.69	-130
-120	332.69	333.81	334.92	336.04	337.16	338.28	339.39	340.51	341.63	342.74	343.86	-120
-110	343.86	344.97	346.09	347.20	348.32	349.43	350.55	351.66	352.77	353.89	355.00	-110
-100	355.00	356.11	357.23	358.34	359.45	360.56	361.67	362.78	363.90	365.01	366.12	-100
-90	366.12	367.23	368.34	369.45	370.56	371.67	372.78	373.89	374.99	376.10	377.21	-90
-80	377.21	378.32	379.43	380.53	381.64	382.75	383.86	384.96	386.07	387.17	388.28	-80
-70	388.28	389.39	390.49	391.60	392.70	393.81	394.91	396.02	397.12	398.22	399.33	-70
-60	399.33	400.43	401.53	402.64	403.74	404.84	405.95	407.05	408.15	409.25	410.35	-60
-50	410.35	411.45	412.55	413.66	414.76	415.86	416.96	418.06	419.16	420.26	421.36	-50
-40	421.36	422.46	423.55	424.65	425.75	426.85	427.95	429.05	430.14	431.24	432.34	-40
-30	432.34	433.44	434.53	435.63	436.73	437.82	438.92	440.02	441.11	442.21	443.30	-30
-20	443.30	444.40	445.49	446.59	447.68	448.78	449.87	450.96	452.06	453.15	454.25	-20
-10	454.25	455.34	456.43	457.52	458.62	459.71	460.80	461.89	462.99	464.08	465.17	-10
0	465.17	466.26	467.35	468.44	469.53	470.62	471.71	472.80	473.89	474.98	476.07	0
10	476.07	477.16	478.25	479.34	480.43	481.52	482.61	483.70	484.78	485.87	486.96	10
20	486.96	488.05	489.14	490.22	491.31	492.40	493.48	494.57	495.66	496.74	497.83	20
30	497.83	498.91	500.00	501.09	502.17	503.26	504.34	505.43	506.51	507.59	508.68	30
40	508.68	509.76	510.85	511.93	513.01	514.10	515.18	516.26	517.35	518.43	519.51	40

Table 8.1.27 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
50	519.51	520.59	521.68	522.76	523.84	524.92	526.00	527.08	528.16	529.24	530.33	50
60	530.33	531.41	532.49	533.57	534.65	535.73	536.81	537.88	538.96	540.04	541.12	60
70	541.12	542.20	543.28	544.36	545.44	546.51	547.59	548.67	549.75	550.82	551.90	70
80	551.90	552.98	554.05	555.13	556.21	557.28	558.36	559.44	560.51	561.59	562.66	80
90	562.66	563.74	564.81	565.89	566.96	568.03	569.11	570.18	571.26	572.33	573.40	90
100	573.40	574.48	575.55	576.62	577.70	578.77	579.84	580.91	581.99	583.06	584.13	100
110	584.13	585.20	586.27	587.34	588.41	589.48	590.56	591.63	592.70	593.77	594.84	110
120	594.84	595.91	596.98	598.04	599.11	600.18	601.25	602.32	603.39	604.46	605.53	120
130	605.53	606.59	607.66	608.73	609.80	610.86	611.93	613.00	614.06	615.13	616.20	130
140	616.20	617.26	618.33	619.39	620.46	621.53	622.59	623.66	624.72	625.78	626.85	140
150	626.85	627.91	628.98	630.04	631.11	632.17	633.23	634.30	635.36	636.42	637.48	150
160	637.48	638.55	639.61	640.67	641.73	642.80	643.86	644.92	645.98	647.04	648.10	160
170	648.10	649.16	650.22	651.28	652.34	653.40	654.46	655.52	656.58	657.64	658.70	170
180	658.70	659.76	660.82	661.88	662.94	663.99	665.05	666.11	667.17	668.23	669.28	180
190	669.28	670.34	671.40	672.45	673.51	674.57	675.62	676.68	677.74	678.79	679.85	190
200	679.85	680.90	681.96	683.01	684.07	685.12	686.18	687.23	688.29	689.34	690.39	200
210	690.39	691.45	692.50	693.55	694.61	695.66	696.71	697.76	698.82	699.87	700.92	210
220	700.92	701.97	703.02	704.08	705.13	706.18	707.23	708.28	709.33	710.38	711.43	220
230	711.43	712.48	713.53	714.58	715.63	716.68	717.73	718.78	719.83	720.87	721.92	230
240	721.92	722.97	724.02	725.07	726.11	727.16	728.21	729.26	730.30	731.35	732.40	240
250	732.40	733.44	734.49	735.54	736.58	737.63	738.67	739.72	740.76	741.81	742.85	250
260	742.85	743.90	744.94	745.99	747.03	748.07	749.12	750.16	751.21	752.25	753.29	260
270	753.29	754.33	755.38	756.42	757.46	758.50	759.55	760.59	761.63	762.67	763.71	270
280	763.71	764.75	765.79	766.83	767.88	768.92	769.96	771.00	772.04	773.08	774.11	280
290	774.11	775.15	776.19	777.23	778.27	779.31	780.35	781.39	782.42	783.46	784.50	290
300	784.50	785.54	786.57	787.61	788.65	789.69	790.72	791.76	792.79	793.83	794.87	300
310	794.87	795.90	796.94	797.97	799.01	800.04	801.08	802.11	803.15	804.18	805.22	310
320	805.22	806.25	807.28	808.32	809.35	810.38	811.42	812.45	813.48	814.51	815.55	320
330	815.55	816.58	817.61	818.64	819.67	820.70	821.74	822.77	823.80	824.83	825.86	330
340	825.86	826.89	827.92	828.95	829.98	831.01	832.04	833.07	834.10	835.13	836.15	340
350	836.15	837.18	838.21	839.24	840.27	841.29	842.32	843.35	844.38	845.40	846.43	350
360	846.43	847.46	848.48	849.51	850.54	851.56	852.59	853.61	854.64	855.67	856.69	360
370	856.69	857.72	858.74	859.76	860.79	861.81	862.84	863.86	864.89	865.91	866.93	370
380	866.93	867.96	868.98	870.00	871.02	872.05	873.07	874.09	875.11	876.13	877.16	380
390	877.16	878.18	879.20	880.22	881.24	882.26	883.28	884.30	885.32	886.34	887.36	390
400	887.36	888.38	889.40	890.42	891.44	892.46	893.48	894.49	895.51	896.53	897.55	400
410	897.55	898.57	899.58	900.60	901.62	902.64	903.65	904.67	905.69	906.70	907.72	410
420	907.72	908.73	909.75	910.77	911.78	912.80	913.81	914.83	915.84	916.86	917.87	420
430	917.87	918.88	919.90	920.91	921.93	922.94	923.95	924.97	925.98	926.99	928.00	430
440	928.00	929.02	930.03	931.04	932.05	933.06	934.08	935.09	936.10	937.11	938.12	440
450	938.12	939.13	940.14	941.15	942.16	943.17	944.18	945.19	946.20	947.21	948.22	450
460	948.22	949.23	950.24	951.24	952.25	953.26	954.27	955.28	956.28	957.29	958.30	460
470	958.30	959.31	960.31	961.32	962.33	963.33	964.34	965.34	966.35	967.36	968.36	470
480	968.36	969.37	970.37	971.38	972.38	973.39	974.39	975.39	976.40	977.40	978.41	480
490	978.41	979.41	980.41	981.42	982.42	983.42	984.42	985.43	986.43	987.43	988.43	490
500	988.43	989.43	990.44	991.44	992.44	993.44	994.44	995.44	996.44	997.44	998.44	500
510	998.44	999.44	1000.44	1001.44	1002.44	1003.44	1004.44	1005.44	1006.43	1007.43	1008.43	510
520	1008.43	1009.43	1010.43	1011.42	1012.42	1013.42	1014.42	1015.41	1016.41	1017.41	1018.40	520
530	1018.40	1019.40	1020.40	1021.39	1022.39	1023.38	1024.38	1025.37	1026.37	1027.36	1028.36	530
540	1028.36	1029.35	1030.35	1031.34	1032.34	1033.33	1034.32	1035.32	1036.31	1037.30	1038.30	540
550	1038.30	1039.29	1040.28	1041.27	1042.27	1043.26	1044.25	1045.24	1046.23	1047.22	1048.21	550
560	1048.21	1049.21	1050.20	1051.19	1052.18	1053.17	1054.16	1055.15	1056.14	1057.13	1058.12	560
570	1058.12	1059.11	1060.09	1061.08	1062.07	1063.06	1064.05	1065.04	1066.02	1067.01	1068.00	570

Table 8.1.27 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
580	1068.00	1068.99	1069.97	1070.96	1071.95	1072.93	1073.92	1074.91	1075.89	1076.88	1077.86	580
590	1077.86	1078.85	1079.84	1080.82	1081.81	1082.79	1083.78	1084.76	1085.74	1086.73	1087.71	590
600	1087.71	1088.70	1089.68	1090.66	1091.65	1092.63	1093.61	1094.59	1095.58	1096.56	1097.54	600
610	1097.54	1098.52	1099.51	1100.49	1101.47	1102.45	1103.43	1104.41	1105.39	1106.37	1107.35	610
620	1107.35	1108.33	1109.31	1110.29	1111.27	1112.25	1113.23	1114.21	1115.19	1116.17	1117.15	620
630	1117.15	1118.13	1119.10	1120.08	1121.06	1122.04	1123.01	1123.99	1134.73	1135.71	1136.68	630
640	1136.68	1137.66	1138.63	1139.60	1140.58	1141.55	1142.53	1143.50	1144.47	1145.45	1146.42	640
650	1146.42	1147.39	1148.37	1149.34	1150.31	1151.28	1152.26	1153.23	1154.20	1155.17	1156.14	650
660	1156.14	1157.11	1158.08	1159.06	1160.03	1161.00	1161.97	1162.94	1163.91	1164.88	1165.85	660
670	1165.85	1166.82	1167.79	1168.75	1169.72	1170.69	1171.55	1172.63	1173.60	1174.57	1175.53	670
680	1165.85	1166.82	1167.79	1168.75	1169.72	1170.69	1171.66	1172.63	1173.60	1174.57	1175.53	680
690	1175.53	1176.50	1177.47	1178.44	1179.40	1180.37	1181.34	1182.30	1183.27	1184.24	1185.20	690
700	1185.20	1186.17	1187.13	1188.10	1189.06	1190.03	1190.99	1191.96	1192.92	1193.89	1194.85	700
710	1194.85	1195.82	1196.78	1197.74	1198.71	1199.67	1200.63	1201.60	1202.56	1203.52	1204.48	710
720	1204.48	1205.45	1206.41	1207.37	1208.33	1209.29	1210.26	1211.22	1212.18	1213.14	1214.10	720
730	1214.10	1215.06	1216.02	1216.98	1217.94	1218.90	1219.86	1220.82	1221.78	1222.74	1223.70	730
740	1223.70	1224.65	1225.61	1226.57	1227.53	1228.49	1229.45	1230.40	1231.36	1232.32	1233.27	740
750	1233.27	1234.23	1235.19	1236.14	1237.10	1238.06	1239.01	1239.97	1240.92	1241.88	1242.84	750
760	1242.84	1243.79	1244.75	1245.70	1246.65	1247.61	1248.56	1249.52	1250.47	1251.42	1252.38	760
770	1252.38	1253.33	1254.28	1255.24	1256.19	1257.14	1258.10	1259.05	1260.00	1260.95	1261.90	770
780	1261.90	1262.85	1263.81	1264.76	1265.71	1266.66	1267.61	1268.56	1269.51	1270.46	1271.41	780
790	1271.41	1272.36	1273.31	1274.26	1275.21	1276.16	1277.11	1278.06	1279.00	1279.95	1280.90	790
800	1280.90	1281.85	1282.80	1283.74	1284.69	1285.64	1286.58	1287.53	1288.48	1289.42	1290.37	800
810	1290.37	1291.32	1292.26	1293.21	1294.15	1295.10	1296.05	1296.99	1297.94	1298.88	1299.82	810
820	1299.82	1300.77	1301.71	1302.66	1303.60	1304.54	1305.49	1306.43	1307.37	1308.32	1309.26	820
830	1309.26	1310.20	1311.15	1312.09	1313.03	1313.97	1314.91	1315.85	1316.80	1317.74	1318.68	830
840	1318.68	1319.62	1320.56	1321.50	1322.44	1323.38	1324.32	1325.26	1326.20	1327.14	1328.08	840
850	1328.08	1329.02	1329.96	1330.89	1331.83	1332.77	1333.71	1334.65	1335.58	1336.52	1337.46	850
860	1337.46	1338.40	1339.33	1340.27	1341.21	1342.14	1343.08	1344.02	1344.95	1345.89	1346.82	860
870	1346.82	1347.76	1348.69	1349.63	1350.56	1351.50	1352.43	1353.37	1354.30	1355.24	1356.17	870
880	1356.17	1357.10	1358.04	1358.97	1359.90	1360.84	1361.77	1362.70	1363.63	1364.57	1365.50	880
890	1365.50	1366.43	1367.36	1368.29	1369.22	1370.15	1371.09	1372.02	1372.95	1373.88	1374.81	890
900	1374.81	1375.74	1376.67	1377.60	1378.53	1379.46	1380.39	1381.31	1382.24	1383.17	1384.10	900
910	1384.10	1385.03	1385.96	1386.88	1387.81	1388.74	1389.67	1390.59	1391.52	1392.45	1393.37	910
920	1393.37	1394.30	1395.23	1396.15	1397.08	1398.00	1398.93	1399.86	1400.78	1401.71	1402.63	920
930	1402.63	1403.56	1404.48	1405.40	1406.33	1407.25	1408.18	1409.10	1410.02	1410.95	1411.87	930
940	1411.87	1412.79	1413.72	1414.64	1415.56	1416.48	1417.40	1418.33	1419.25	1420.17	1421.09	940
950	1421.09	1422.01	1422.93	1423.85	1424.77	1425.69	1426.61	1427.53	1428.45	1429.37	1430.29	950
960	1430.29	1431.21	1432.13	1433.05	1433.97	1434.89	1435.81	1436.72	1437.64	1438.56	1439.48	960
970	1439.48	1440.40	1441.31	1442.23	1443.15	1444.06	1444.98	1445.90	1446.81	1447.73	1448.64	970
980	1448.64	1449.56	1450.48	1451.39	1452.31	1453.22	1454.14	1455.05	1455.97	1456.88	1457.79	980
990	1457.79	1458.71	1459.62	1460.54	1461.45	1462.36	1463.27	1464.19	1465.10	1466.01	1466.92	990
1000	1466.92	1467.84	1468.75	1469.66	1470.57	1471.48	1472.40	1473.31	1474.22	1475.13	1476.04	1000
1010	1476.04	1476.95	1477.86	1478.77	1479.68	1480.59	1481.50	1482.41	1483.32	1484.22	1485.13	1010
1020	1485.13	1486.04	1486.95	1487.86	1488.77	1489.67	1490.58	1491.49	1492.40	1493.30	1494.21	1020
1030	1494.21	1495.12	1496.02	1496.93	1497.84	1498.74	1499.65	1500.55	1501.46	1502.37	1503.27	1030
1040	1503.27	1504.18	1505.08	1505.98	1506.89	1507.79	1508.70	1509.60	1510.51	1511.41	1512.31	1040
1050	1512.31	1513.22	1514.12	1515.02	1515.92	1516.83	1517.73	1518.63	1519.53	1520.43	1521.34	1050
1060	1521.34	1522.24	1523.14	1524.04	1524.94	1525.84	1526.74	1527.64	1528.54	1529.44	1530.34	1060
1070	1530.34	1531.24	1532.14	1533.04	1533.94	1534.84	1535.74	1536.63	1537.53	1538.43	1539.33	1070
1080	1539.33	1540.23	1541.12	1542.02	1542.92	1543.82	1544.71	1545.61	1546.51	1547.40	1548.30	1080
1090	1548.30	1549.20	1550.09	1550.99	1551.88	1552.78	1553.67	1554.57	1555.46	1556.36	1557.25	1090
1100	1557.25	1558.15	1559.04	1559.93	1560.83	1561.72	1562.61	1563.51	1564.40	1565.29	1566.19	1100

Table 8.1.27 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
1110	1566.19	1567.08	1567.97	1568.86	1569.75	1570.65	1571.54	1572.43	1573.32	1574.21	1575.10	1110
1120	1575.10	1575.99	1576.88	1577.77	1578.66	1579.55	1580.44	1581.33	1582.22	1583.11	1584.00	1120
1130	1584.00	1584.89	1585.78	1586.67	1587.55	1588.44	1589.33	1590.22	1591.11	1591.99	1592.88	1130
1140	1592.88	1593.77	1594.65	1595.54	1596.43	1597.31	1598.20	1599.09	1599.97	1600.86	1601.74	1140
1150	1601.74	1602.63	1603.51	1604.40	1605.28	1606.17	1607.05	1607.94	1608.82	1609.70	1610.59	1150
1160	1610.59	1611.47	1612.35	1613.24	1614.12	1615.00	1615.89	1616.77	1617.65	1618.53	1619.41	1160
1170	1619.41	1620.30	1621.18	1622.06	1622.94	1623.82	1624.70	1625.58	1626.46	1627.34	1628.22	1170
1180	1628.22	1629.10	1629.98	1630.86	1631.74	1632.62	1633.50	1634.38	1635.26	1636.14	1637.01	1180
1190	1637.01	1637.89	1638.77	1639.65	1640.53	1641.40	1642.28	1643.16	1644.03	1644.91	1645.79	1190
1200	1645.79	1646.66	1647.54	1648.42	1649.29	1650.17	1651.04	1651.92	1652.79	1653.67	1654.54	1200
1210	1654.54	1655.42	1656.29	1657.17	1658.04	1658.91	1659.79	1660.66	1661.53	1662.41	1663.28	1210
1220	1663.28	1664.15	1665.02	1665.90	1666.77	1667.64	1668.51	1669.38	1670.26	1671.13	1672.00	1220
1230	1672.00	1672.87	1673.74	1674.61	1675.48	1676.35	1677.22	1678.09	1678.96	1679.83	1680.70	1230
1240	1680.70	1681.57	1682.44	1683.31	1684.18	1685.04	1685.91	1686.78	1687.65	1688.52	1689.38	1240
1250	1689.38	1690.25	1691.12	1691.98	1692.85	1693.72	1694.58	1695.45	1696.32	1697.18	1698.05	1250
1260	1698.05	1698.91	1699.78	1700.65	1701.51	1702.37	1703.24	1704.10	1704.97	1705.83	1706.70	1260
1270	1706.70	1707.56	1708.42	1709.29	1710.15	1711.01	1711.88	1712.74	1713.60	1714.46	1715.33	1270
1280	1715.33	1716.19	1717.05	1717.91	1718.77	1719.63	1720.50	1721.36	1722.22	1723.08	1723.94	1280
1290	1723.94	1724.80	1725.66	1726.52	1727.38	1728.24	1729.10	1729.96	1730.81	1731.67	1732.53	1290
1300	1732.53	1733.39	1734.25	1735.11	1735.96	1736.82	1737.68	1738.54	1739.39	1740.25	1741.11	1300
1310	1741.11	1741.96	1742.82	1743.68	1744.53	1745.39	1746.24	1747.10	1747.96	1748.81	1749.67	1310
1320	1749.67	1750.52	1751.38	1752.23	1753.08	1753.94	1754.79	1755.65	1756.50	1757.35	1758.21	1320
1330	1758.21	1759.06	1759.91	1760.76	1761.62	1762.47	1763.32	1764.17	1765.03	1765.88	1766.73	1330
1340	1766.73	1767.58	1768.43	1769.28	1770.13	1770.98	1771.83	1772.68	1773.53	1774.38	1775.23	1340
1350	1775.23	1776.08	1776.93	1777.78	1778.63	1779.48	1780.33	1781.18	1782.02	1782.87	1783.72	1350
1360	1783.72	1784.57	1785.41	1786.26	1787.11	1787.96	1788.80	1789.65	1790.50	1791.34	1792.19	1360
1370	1792.19	1793.03	1793.88	1794.72	1795.57	1796.42	1797.26	1798.11	1798.95	1799.79	1800.64	1370
1380	1800.64	1801.48	1802.33	1803.17	1804.01	1804.86	1805.70	1806.54	1807.39	1808.23	1809.07	1380
1390	1809.07	1809.91	1810.76	1811.60	1812.44	1813.28	1814.12	1814.96	1815.80	1816.65	1817.49	1390
1400	1817.49	1818.33	1819.17	1820.01	1820.85	1821.69	1822.53	1823.37	1824.21	1825.04	1825.88	1400
1410	1825.88	1826.72	1827.56	1828.40	1829.24	1830.07	1830.91	1831.75	1832.59	1833.42	1834.26	1410
1420	1834.26	1835.10	1835.94	1836.77	1837.61	1838.44	1839.28	1840.12	1840.95	1841.79	1842.62	1420
1430	1842.62	1843.46	1844.29	1845.13	1845.96	1846.80	1847.63	1848.47	1849.30	1850.13	1850.97	1430
1440	1850.97	1851.80	1852.63	1853.47	1854.30	1855.13	1855.96	1856.80	1857.63	1858.46	1859.29	1440
1450	1859.29	1860.12	1860.95	1861.79	1862.62	1863.45	1864.28	1865.11	1865.94	1866.77	1867.60	1450
1460	1867.60	1868.43	1869.26	1870.09	1870.92	1871.75	1872.57	1873.40	1874.23	1875.06	1875.89	1460
1470	1875.89	1876.72	1877.54	1878.37	1879.20	1880.03	1880.85	1881.68	1882.51	1883.33	1884.16	1470
1480	1884.16	1884.99	1885.81	1886.64	1887.46	1888.29	1889.11	1889.94	1890.76	1891.59	1892.41	1480
1490	1892.41	1893.24	1894.06	1894.89	1895.71	1896.53	1897.36	1898.18	1899.00	1899.83	1900.65	1490
1500	1900.65	1901.47	1902.29	1903.12	1903.94	1904.76	1905.58	1906.40	1907.23	1908.05	1908.87	1500
1510	1908.87	1909.69	1910.51	1911.33	1912.15	1912.97	1913.79	1914.61	1915.43	1916.25	1917.07	1510
1520	1917.07	1917.89	1918.71	1919.52	1920.34	1921.16	1921.98	1922.80	1923.61	1924.43	1925.25	1520
1530	1925.25	1926.07	1926.88	1927.70	1928.52	1929.33	1930.15	1930.97	1931.78	1932.60	1933.41	1530
1540	1933.41	1934.23	1935.04	1935.86	1936.67	1937.49	1938.30	1939.12	1939.93	1940.75	1941.56	1540
1550	1941.56	1942.37	1943.19	1944.00	1944.81	1945.63	1946.44	1947.25	1948.06	1948.88	1949.69	1550
1560	1949.69	1950.50	1951.31									1560

Nickel 120

Resistance as a Function of Temperature (°C)
Reference Standard: Edison Curve 7

Table 8.1.28 Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-70	73.10	73.75	74.40	75.05	75.71	76.36	77.01	77.66	78.31	78.97	79.62	-70
-60	79.62	80.27	80.93	81.58	82.24	82.89	83.55	84.20	84.86	85.51	86.17	-60
-50	86.17	86.83	87.48	88.14	88.80	89.46	90.12	90.78	91.44	92.10	92.76	-50
-40	92.76	93.42	94.08	94.75	95.41	96.08	96.74	97.41	98.08	98.74	99.41	-40
-30	99.41	100.08	100.75	101.42	102.09	102.77	103.44	104.12	104.79	105.47	106.15	-30
-20	106.15	106.83	107.51	108.19	108.87	109.56	110.24	110.93	111.62	112.31	113.00	-20
-10	113.00	113.69	114.39	115.08	115.78	116.48	117.18	117.88	118.59	119.29	120.00	-10
0	120.00	120.71	121.42	122.13	122.85	123.56	124.28	125.00	125.72	126.44	127.17	0
10	127.17	127.90	128.62	129.35	130.09	130.82	131.56	132.29	133.03	133.77	134.52	10
20	134.52	135.24	134.01	134.76	137.51	138.26	139.02	139.77	140.53	141.29	142.06	20
30	142.06	142.82	143.59	144.36	145.13	145.90	146.68	147.45	148.23	149.01	149.80	30
40	149.80	150.58	151.37	152.16	152.95	153.74	154.54	155.34	156.14	156.94	157.74	40
50	157.74	158.55	159.36	160.17	160.98	161.79	162.61	163.43	164.25	165.07	165.90	50
60	165.90	166.73	167.56	168.39	169.22	170.06	170.89	171.73	172.58	173.42	174.27	60
70	174.27	175.11	175.97	176.82	177.67	178.53	179.39	180.25	181.11	181.98	182.85	70
80	182.85	183.72	184.59	185.46	186.34	187.22	188.10	188.98	189.86	190.75	191.64	80
90	191.64	192.53	193.42	194.32	195.21	196.11	197.02	197.92	198.83	199.73	200.64	90
100	200.64	201.56	202.47	203.39	204.31	205.23	206.15	207.08	208.00	208.93	209.86	100
110	209.86	210.80	211.73	212.67	213.61	214.55	215.50	216.45	217.40	218.35	219.30	110
120	219.30	220.26	221.21	222.17	223.14	224.10	225.07	226.04	227.01	227.98	228.96	120
130	228.96	229.94	230.92	231.90	232.89	233.87	234.86	235.86	236.85	237.85	238.85	130
140	238.85	239.85	240.85	241.86	242.87	243.88	244.89	245.91	246.93	247.95	248.97	140
150	248.97	250.01	251.04	252.08	253.12	254.16	255.20	256.24	257.28	258.32	259.37	150
160	259.37	260.41	261.46	262.51	263.56	264.62	265.67	266.73	267.80	268.86	269.93	160
170	269.93	271.00	272.07	273.15	274.23	275.31	276.40	277.49	278.58	279.68	280.78	170
180	280.78	281.88	282.99	284.10	285.21	286.33	287.45	288.57	289.70	290.83	291.96	180
190	291.96	293.10	294.24	295.38	296.53	297.68	298.83	299.98	301.14	302.30	303.46	190
200	303.46	304.63	305.80	306.97	308.15	309.34	310.52	311.71	312.90	314.10	315.30	200
210	315.30	316.51	317.72	318.93	320.15	321.37	322.59	323.82	325.05	326.29	327.53	210
220	327.53	328.77	330.02	331.27	332.53	333.79	335.05	336.32	337.59	338.86	340.14	220
230	340.14	341.43	342.71	344.00	345.30	346.59	347.90	349.20	350.51	351.82	353.14	230
240	353.14	354.46	355.79	357.12	358.45	359.79	361.13	362.47	363.82	365.17	366.53	240
250	366.53	367.89	369.25	370.62	371.99	373.37	374.75	376.13	377.52	378.91	380.31	250
260	380.31	381.71	383.11	384.52	385.93	387.35	388.77	390.19	391.62	393.05	394.49	260
270	394.49	395.93	397.37	398.82	400.27	401.73	403.19	404.65	406.12	407.59	409.07	270
280	409.07	410.55	412.03	413.52	415.01	416.51	418.01	419.51	421.02	422.53	424.05	280
290	424.05	425.57	427.09	428.62	430.15	431.69	433.23	434.77	436.32	437.87	439.43	290

Nickel 120

Resistance as a Function of Temperature (°F)
Reference Standard: Edison Curve 7

Table 8.1.29 Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-90	74.55	74.91	75.27	75.63	76.00	76.36	76.72	77.08	77.44	77.81	78.17	-90
-80	78.17	78.53	78.90	79.26	79.62	79.98	80.35	80.71	81.07	81.44	81.80	-80
-70	81.80	82.16	82.53	82.89	83.25	83.62	83.98	84.35	84.71	85.08	85.44	-70
-60	85.44	85.80	86.17	86.53	86.90	87.26	87.63	87.99	88.36	88.73	89.09	-60
-50	89.09	89.46	89.82	90.19	90.56	90.92	91.29	91.66	92.02	92.39	92.76	-50
-40	92.76	93.13	93.50	93.86	94.23	94.60	94.97	95.34	95.71	96.08	96.45	-40
-30	96.45	96.82	97.19	97.56	97.93	98.30	98.67	99.04	99.41	99.78	100.16	-30
-20	100.16	100.53	100.90	101.27	101.65	102.02	102.39	102.77	103.14	103.52	103.89	-20
-10	103.89	104.27	104.64	105.02	105.40	105.77	106.15	106.53	1096.90	107.28	107.66	-10
0	107.66	108.44	108.42	108.80	109.18	109.56	109.94	110.32	110.70	111.08	111.47	0
10	111.47	111.85	112.23	112.62	113.00	113.39	113.77	114.16	114.54	114.93	115.32	10
20	115.32	115.70	116.09	116.48	116.87	117.26	117.65	118.04	118.43	118.82	119.21	20
30	119.21	119.61	120.00	120.39	120.79	121.18	121.58	121.98	122.37	122.77	123.17	30
40	123.17	123.56	123.96	124.36	124.76	125.16	125.56	125.96	126.36	126.77	127.17	40
50	127.17	127.57	127.98	128.38	128.79	129.19	129.60	130.0	130.41	130.82	131.23	50
60	131.23	131.64	132.05	132.46	132.87	133.28	133.69	134.10	134.52	134.93	135.35	60
70	135.35	135.76	136.18	136.59	137.01	137.43	137.84	138.26	138.68	139.10	139.52	70
80	139.52	139.94	140.36	140.79	141.21	141.63	142.06	142.48	142.91	143.33	143.76	80
90	143.76	144.19	144.61	145.04	145.47	145.90	146.33	146.76	147.19	147.63	148.06	90
100	148.06	148.49	148.93	149.36	149.80	150.23	150.67	151.11	151.54	151.98	152.42	100
110	152.42	152.86	153.30	153.74	154.19	154.63	155.07	155.52	155.96	156.40	156.85	110
120	156.85	157.30	157.74	158.19	158.64	159.09	159.54	159.99	160.44	160.89	161.34	120
130	161.34	161.9	162.25	162.70	163.16	163.61	164.07	164.53	164.98	165.44	165.90	130
140	165.90	166.36	166.82	167.28	167.74	168.20	168.66	169.13	169.59	170.06	170.52	140
150	170.52	170.99	171.45	171.92	172.39	172.86	173.33	173.80	174.27	174.74	175.21	150
160	175.21	175.68	176.15	176.63	177.10	177.58	178.05	178.53	179.01	179.48	179.96	160
170	179.96	180.44	180.92	181.40	181.88	182.36	182.85	183.33	183.81	184.30	184.78	170
180	184.78	185.27	185.75	186.24	186.73	187.22	187.70	188.19	188.68	189.17	189.67	180
190	189.67	190.16	190.65	191.14	191.64	192.13	192.63	193.12	193.62	194.12	194.62	190
200	194.62	195.12	195.61	196.11	196.62	197.12	197.62	198.12	198.62	199.13	199.63	200
210	199.63	200.12	200.64	201.15	201.66	202.17	202.67	203.18	203.69	204.20	204.71	210
220	204.71	205.23	205.74	206.25	206.77	207.28	207.80	208.31	208.83	209.35	209.86	220
230	209.86	210.38	210.93	211.42	211.94	212.46	212.98	213.51	214.03	214.55	215.08	230
240	215.08	215.60	216.13	216.66	217.18	217.71	218.24	218.77	219.30	219.83	220.36	240
250	220.36	220.89	221.43	221.96	222.50	223.03	223.57	224.10	224.64	225.18	225.71	250
260	225.71	226.25	226.79	227.33	227.87	228.42	228.96	229.50	230.05	230.59	231.14	260
270	231.41	231.68	232.23	232.78	233.32	233.87	234.42	234.97	235.52	236.08	236.63	270
280	236.63	237.18	237.74	238.29	238.85	239.40	239.96	240.52	241.08	241.63	242.19	280
290	242.19	242.75	243.32	243.88	244.44	245.01	245.57	246.13	246.70	247.27	247.83	290
300	247.83	248.40	248.97	249.55	250.12	250.70	251.27	251.85	252.43	253.00	253.58	300
310	253.58	254.16	254.73	255.31	255.89	256.47	257.05	257.63	258.20	258.78	259.37	310
320	259.37	259.95	260.53	261.11	261.69	262.28	262.86	263.45	264.03	264.62	265.20	320
330	265.20	265.79	266.38	266.97	267.56	268.15	268.74	269.34	269.93	270.52	271.12	330
340	271.12	271.72	272.31	272.91	273.51	274.11	274.71	275.31	275.92	276.52	277.13	340
350	277.13	277.73	278.34	278.95	279.56	280.17	280.78	281.39	282.01	282.62	283.24	350
360	283.24	283.85	284.47	285.09	285.71	286.33	286.95	287.58	288.20	288.82	289.45	360
370	289.45	290.08	290.71	291.33	291.96	292.60	293.23	293.86	294.49	295.13	295.76	370

Table 8.1.29 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
380	295.76	296.40	297.04	297.68	298.32	298.96	299.60	300.24	300.88	301.52	302.17	380
390	302.17	302.81	303.46	304.11	304.76	305.41	306.06	306.71	307.37	308.02	308.68	390
400	308.68	309.34	309.99	310.65	311.31	311.98	312.64	313.30	313.97	314.64	315.30	400
410	315.30	315.97	316.64	317.31	317.99	318.66	319.34	320.01	320.69	321.37	322.05	410
420	322.05	322.73	323.41	324.10	324.78	325.47	326.15	326.84	327.53	328.22	328.91	420
430	328.91	329.61	330.30	330.99	331.69	332.39	333.09	333.79	334.49	335.19	335.90	430
440	335.90	336.60	337.31	338.01	338.72	339.43	340.14	340.85	341.57	342.28	343.00	440
450	343.00	343.72	344.43	345.15	345.87	346.59	347.32	348.04	348.77	349.49	350.22	450
460	350.22	350.95	351.68	352.41	353.14	353.88	354.61	355.35	356.08	356.82	357.56	460
470	357.56	358.30	359.04	359.79	360.53	361.28	362.02	362.77	363.52	364.27	365.02	470
480	365.02	365.77	366.53	367.29	368.04	368.80	369.56	370.32	371.08	371.84	372.61	480
490	372.61	373.37	374.14	374.90	375.67	376.44	377.21	377.99	378.76	379.53	380.31	490
500	380.31	381.09	381.87	382.65	383.43	384.21	384.99	385.78	386.56	387.35	388.14	500
510	388.14	388.93	389.72	390.51	391.30	392.10	392.89	393.69	394.49	395.29	396.09	510
520	396.09	396.89	397.70	398.50	399.31	400.11	400.92	401.73	402.54	403.35	404.17	520
530	404.17	404.98	405.80	406.61	407.43	408.25	409.07	409.89	410.71	411.54	412.36	530
540	412.36	413.19	414.02	414.85	415.68	416.51	417.34	418.18	419.01	419.85	420.69	540
550	420.69	421.53	422.37	423.21	424.05	424.89	425.74	426.59	427.43	428.28	429.13	550
560	429.13	429.98	430.84	431.69	432.55	433.40	434.26	435.12	435.98	436.84	437.70	560
570	437.70	438.57	439.43									570

Copper 10

Resistance as a Function of Temperature (°C)
Reference Standard: SAMA RC21-4-1996

Table 8.1.30 Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
-70	6.33	6.37	6.41	6.45	6.49	6.53	6.57	6.60	6.64	6.68	6.72	-70
-60	6.72	6.76	6.80	6.84	6.88	6.92	6.96	6.99	7.03	7.07	7.11	-60
-50	7.11	7.15	7.19	7.23	7.27	7.31	7.34	7.38	7.42	7.46	7.50	-50
-40	7.50	7.54	7.58	7.62	7.65	7.69	7.73	7.77	7.81	7.85	7.89	-40
-30	7.89	7.92	7.96	8.00	8.04	8.08	8.12	8.16	8.19	8.23	8.27	-30
-20	8.27	8.31	8.35	8.39	8.43	8.46	8.50	8.54	8.58	8.62	8.66	-20
-10	8.66	8.70	8.73	8.77	8.81	8.85	8.89	8.93	8.97	9.00	9.04	-10
0	9.04	9.08	9.12	9.16	9.20	9.23	9.27	9.31	9.35	9.39	9.43	0
10	9.43	9.47	9.50	9.54	9.58	9.62	9.66	9.70	9.74	9.77	9.81	10
20	9.81	9.85	9.89	9.93	9.97	10.01	10.04	10.08	10.12	10.16	10.20	20
30	10.20	10.24	10.27	10.31	10.35	10.39	10.43	10.47	10.51	10.54	10.58	30
40	10.58	10.62	10.66	10.70	10.74	10.78	10.81	10.85	10.89	10.93	10.97	40
50	10.97	11.01	11.05	11.08	11.12	11.16	11.20	11.24	11.28	11.31	11.35	50
60	11.35	11.39	11.43	11.47	11.51	11.55	11.58	11.62	11.66	11.70	11.74	60
70	11.74	11.78	11.82	11.85	11.89	11.93	11.97	12.01	12.05	12.09	12.12	70
80	12.12	12.16	12.20	12.24	12.28	12.32	12.35	12.39	12.43	12.47	12.51	80
90	12.51	12.55	12.59	12.62	12.66	12.70	12.74	12.78	12.82	12.86	12.89	90
100	12.89	12.93	12.97	13.01	13.05	13.09	13.13	13.16	13.20	13.24	13.28	100
110	13.28	13.32	13.36	13.39	13.43	13.47	13.51	13.55	13.59	13.63	13.66	110
120	13.66	13.70	13.74	13.78	13.82	13.86	13.90	13.93	13.97	14.01	14.05	120
130	14.05	14.09	14.13	14.17	14.20	14.24	14.28	14.32	14.36	14.40	14.43	130
140	14.43	14.47	14.51	14.55	14.59	14.63	14.67	14.70	14.74	14.78	14.82	140
150	14.82	14.86	14.90	14.94	14.97	15.01	15.05	15.09	15.13	15.17	15.21	150

Table 8.1.30 cont. Resistance in Ohms

°C	0	1	2	3	4	5	6	7	8	9	10	°C
160	15.21	15.24	15.28	15.32	15.36	15.40	15.44	15.47	15.51	15.55	15.59	160
170	15.59	15.63	15.67	15.71	15.74	15.78	15.82	15.86	15.90	15.94	15.98	170
180	15.98	16.01	16.05	16.09	16.13	16.17	16.21	16.25	16.28	16.32	16.36	180
190	16.36	16.40	16.44	16.48	16.51	16.55	16.59	16.63	16.67	16.71	16.75	190
200	16.75	16.78	16.82	16.86	16.90	16.94	16.98	17.02	17.05	17.09	17.13	200
210	1713	17.17	17.21	17.25	17.29	17.32	17.36	17.40	17.44	17.48	17.52	210
220	17.52	17.55	17.59	17.63	17.67	17.71	17.75	17.79	17.82	17.86	17.90	220
230	17.90	17.94	17.98	18.02	18.06	18.09	18.13	18.17	18.21	18.25	18.29	230
240	18.29	18.33	18.36	18.40	18.44	18.48	18.52	18.56	18.59	18.63	18.67	240

Copper 10

Resistance as a Function of Temperature (°F)
Reference Standard: SAMA RC21-4-1996

Table 8.1.31 Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
-90	6.42	6.44	6.46	6.48	6.51	6.53	6.55	6.57	6.59	6.61	6.64	-90
-80	6.64	6.66	6.68	6.70	6.72	6.74	6.77	6.79	6.81	6.83	6.85	-80
-70	6.85	6.87	6.89	6.92	6.94	6.96	6.98	7.00	7.02	7.05	7.07	-70
-60	7.07	7.09	7.11	7.13	7.15	7.18	7.20	7.22	7.24	7.26	7.28	-60
-50	7.28	7.31	7.33	7.35	7.37	7.39	7.41	7.43	7.46	7.48	7.50	-50
-40	7.50	7.52	7.54	7.56	7.59	7.61	7.63	7.65	7.67	7.69	7.71	-40
-30	7.71	7.74	7.76	7.78	7.80	7.82	7.84	7.86	7.89	7.91	7.93	-30
-20	7.93	7.95	7.97	7.99	8.01	8.04	8.06	8.08	8.10	8.12	8.14	-20
-10	8.14	8.16	8.19	8.21	8.23	8.25	8.27	8.29	8.31	8.34	8.36	-10
0	8.36	8.38	8.40	8.42	8.44	8.46	8.49	8.51	8.53	8.55	8.57	0
10	8.57	8.59	8.61	8.64	8.66	8.68	8.70	8.72	8.74	8.76	8.79	10
20	8.79	8.81	8.83	8.85	8.87	8.89	8.91	8.94	8.96	8.98	9.00	20
30	9.00	9.02	9.04	9.06	9.08	9.11	9.13	9.15	9.17	9.19	9.21	30
40	9.21	9.23	9.26	9.28	9.30	9.32	9.34	9.36	9.38	9.41	9.43	40
50	9.43	9.45	9.47	9.49	9.51	9.53	9.56	9.58	9.60	9.62	9.64	50
60	9.64	9.66	9.68	9.71	9.73	9.75	9.77	9.79	9.81	9.83	9.86	60
70	9.86	9.88	9.90	9.92	9.94	9.96	9.98	10.01	10.03	10.05	10.07	70
80	10.07	10.09	10.11	10.13	10.15	10.18	10.20	10.22	10.24	10.26	10.28	80
90	10.28	10.30	10.33	10.35	10.37	10.39	10.41	10.43	10.45	10.48	10.50	90
100	10.50	10.52	10.54	10.56	10.58	10.60	10.63	10.65	10.67	10.69	10.71	100
110	10.71	10.73	10.75	10.78	10.80	10.82	10.84	10.86	10.88	10.90	10.93	110
120	10.93	10.95	10.97	10.99	11.01	11.03	11.05	11.08	11.10	11.12	11.14	120
130	11.14	11.16	11.18	11.20	11.22	11.25	11.27	11.29	11.31	11.33	11.35	130
140	11.35	11.37	11.40	11.42	11.44	11.46	11.48	11.50	11.52	11.55	11.57	140
150	11.57	11.59	11.61	11.63	11.65	11.67	11.70	11.72	11.74	11.76	11.78	150
160	11.78	11.80	11.82	11.85	11.87	11.89	11.91	11.93	11.95	11.97	12.00	160
170	12.00	12.02	12.04	12.06	12.08	12.10	12.12	12.15	12.17	12.19	12.21	170
180	12.21	12.23	12.25	12.27	12.29	12.32	12.34	12.36	12.38	12.40	12.42	180
190	12.42	12.44	12.47	12.49	12.51	12.53	12.55	12.57	12.59	12.62	12.64	190
200	12.64	12.66	12.68	12.70	12.72	12.74	12.77	12.79	12.81	12.83	12.85	200
210	12.85	12.87	12.89	12.92	12.94	12.96	12.98	13.00	13.02	13.04	13.07	210
220	13.07	13.09	13.11	13.13	13.15	13.17	13.19	13.22	13.24	13.26	13.28	220
230	13.28	13.30	13.32	13.34	13.36	13.39	13.41	13.43	13.45	13.47	13.49	230
240	13.49	13.51	13.54	13.56	13.58	13.60	13.62	13.64	13.66	13.69	13.71	240

Table 8.1.31 cont. Resistance in Ohms

°F	0	1	2	3	4	5	6	7	8	9	10	°F
250	13.71	13.73	13.75	13.77	13.79	13.81	13.84	13.86	13.88	13.90	13.92	250
260	13.92	13.94	13.96	13.99	14.01	14.03	14.05	14.07	14.09	14.11	14.14	260
270	14.14	14.16	14.18	14.20	14.22	14.24	14.26	14.29	14.31	14.33	14.35	270
280	14.35	14.37	14.39	14.41	14.43	14.46	14.48	14.50	14.52	14.54	14.56	280
290	14.56	14.58	14.61	14.63	14.65	14.67	14.69	14.71	14.73	14.76	14.78	290
300	14.78	14.80	14.82	14.84	14.86	14.88	14.91	14.93	14.95	14.97	14.99	300
310	14.99	15.01	15.03	15.06	15.08	15.10	15.12	15.14	15.16	15.18	15.21	310
320	15.21	15.23	15.25	15.28	15.29	15.31	15.33	15.36	15.38	15.40	15.42	320
330	15.42	15.44	15.46	15.48	15.50	15.53	15.55	15.57	15.59	15.61	15.63	330
340	15.63	15.65	15.68	15.70	15.72	15.74	15.76	15.78	15.80	15.83	15.85	340
350	15.85	15.87	15.89	15.91	15.93	15.95	15.98	16.00	16.02	16.04	16.06	350
360	16.06	16.08	16.10	16.13	16.15	16.17	16.19	16.21	16.23	16.25	16.28	360
370	16.28	16.30	16.32	16.34	16.36	16.38	16.40	16.43	16.45	16.47	16.49	370
380	16.49	16.51	16.53	16.55	16.57	16.60	16.62	16.64	16.66	16.68	16.70	380
390	16.70	16.72	16.75	16.77	16.79	16.81	16.83	16.85	16.87	16.90	16.92	390
400	16.92	16.94	16.96	16.98	17.00	17.02	17.05	17.07	17.09	17.11	17.13	400
410	17.13	17.15	17.17	17.20	17.22	17.24	17.26	17.28	17.30	17.32	17.35	410
420	17.35	17.37	17.39	17.41	17.43	17.45	17.47	17.50	17.52	17.54	17.56	420
430	17.56	17.58	17.60	17.62	17.64	17.67	17.69	17.71	17.73	17.75	17.77	430
440	17.77	17.79	17.82	17.84	17.86	17.88	17.90	17.92	17.94	17.97	17.99	440
450	17.99	18.01	18.03	18.05	18.07	18.09	18.12	18.14	18.16	18.18	18.20	450
460	18.20	18.22	18.24	18.27	18.29	18.31	18.33	18.35	18.37	18.39	18.42	460
470	18.42	18.44	18.46	18.48	18.50	18.52	18.54	18.57	18.59	18.61	18.63	470
480	18.63	18.65	18.67									480

8.2 – Conversion Data

Table 8.2.1 Temperature Conversion

-459.4° to 0°			1° to 60°			61° to 290°			300° to 890°			900° to 3000°		
C	F C	F	C	F C	F	C	F C	F	C	F C	F	C	F C	F
-273	-459.4		-17.2	1	33.8	16.1	61	141.8	149	300	572	482	900	1652
-268	-450		-16.7	2	35.6	16.7	62	143.6	154	310	590	488	910	1670
-262	-440		-16.1	3	37.4	17.2	63	145.4	160	320	608	493	920	1688
-257	-430		-15.6	4	39.2	17.8	64	147.2	166	330	626	499	930	1706
-251	-420		-15.0	5	41.0	18.3	65	149.0	171	340	644	504	940	1724
-246	-410		-14.4	6	42.8	18.9	66	150.8	177	350	662	510	950	1742
-240	-400		-13.9	7	44.6	19.4	67	152.6	182	360	680	516	960	1760
-234	-390		-13.3	8	46.4	20.0	68	154.4	188	370	698	521	970	1778
-229	-380		-12.8	9	48.2	20.6	69	156.2	193	380	716	527	980	1796
-223	-370		-12.2	10	50.0	21.1	70	158.0	199	390	734	532	990	1814
-218	-360		-11.7	11	51.8	21.7	71	159.8	204	400	752	538	1000	1832
-212	-350		-11.1	12	53.6	22.2	72	161.6	210	410	770	549	1020	1868
-207	-340		-10.6	13	55.4	22.8	73	163.4	216	420	788	560	1040	1904
-201	-330		-10.0	14	57.2	23.3	74	165.2	221	430	806	571	1060	1940
-196	-320		-9.4	15	59.0	23.9	75	167.0	227	440	824	582	1080	1976
-190	-310		-8.9	16	60.8	24.4	76	168.8	232	450	842	593	1100	2012
-184	-300		-8.3	17	62.6	25.0	77	170.6	238	460	860	604	1120	2048
-179	-290		-7.8	18	64.4	25.6	78	172.4	243	470	878	616	1140	2084
-173	-280		-7.2	19	66.2	26.1	79	174.2	249	480	896	627	1160	2120
-169	-273	-459.4	-6.7	20	68.0	26.7	80	176.0	254	490	914	638	1180	2156
-168	-270	-454	-6.1	21	69.8	27.2	81	177.8	260	500	932	649	1200	2192
-162	-260	-436	-5.6	22	71.6	27.8	82	179.6	266	510	950	660	1220	2228
-157	-250	-418	-5.0	23	73.4	28.3	83	181.4	271	520	968	671	1240	2264
-151	-240	-400	-4.4	24	75.2	28.9	84	183.2	277	530	986	682	1260	2300
-146	-230	-382	-3.9	25	77.0	29.4	85	185.0	282	540	1004	693	1280	2336
-140	-220	-364	-3.3	26	78.8	30.0	86	186.8	288	550	1022	704	1300	2372
-134	-210	-346	-2.8	27	80.6	30.6	87	188.6	293	560	1040	732	1350	2462
-129	-200	-328	-2.2	28	82.4	31.1	88	190.4	299	570	1058	760	1400	2552
-123	-190	-310	-1.7	29	84.2	31.7	89	192.2	304	580	1076	788	1450	2642
-118	-180	-292	-1.1	30	86.0	32.2	90	194.0	310	590	1094	816	1500	2732
-112	-170	-274	-0.6	31	87.8	32.8	91	195.8	316	600	1112	843	1550	2822
-107	-160	-256	0.0	32	89.6	33.3	92	197.6	321	610	1130	871	1600	2912
-101	-150	-238	0.6	33	91.4	33.9	93	199.4	327	620	1148	899	1650	3002
-96	-140	-220	1.1	34	93.2	34.4	94	201.2	332	630	1166	927	1700	3092
-90	-130	-202	1.7	35	95.0	35.0	95	203.0	338	640	1184	954	1750	3182
-84	-120	-184	2.2	36	96.8	35.6	96	204.8	343	650	1202	982	1800	3272
-79	-110	-166	2.8	37	98.6	36.1	97	206.6	349	660	1220	1010	1850	3362
-73	-100	-148	3.3	38	100.4	36.7	98	208.4	354	670	1238	1038	1900	3452
-68	-90	-130	3.9	39	102.2	37.2	99	210.2	360	680	1256	1066	1950	3542
-62	-80	-112	4.4	40	104.0	37.8	100	212.0	366	690	1274	1093	2000	3632
-57	-70	-94	5.0	41	105.8	43	110	230	371	700	1292	1121	2050	3722

Table 8.2.1 cont. Temperature Conversion[1]

-459.4° to 0°			1° to 60°			61° to 290°			300° to 890°			900° to 3000°		
-51	-60	-76	5.6	42	107.6	49	120	248	377	710	1310	1149	2100	3812
-46	-50	-58	6.1	43	109.4	54	130	266	382	720	1328	1177	2150	3902
-40	-40	-40	6.7	44	111.2	60	140	284	388	730	1346	1204	2200	3992
-34	-30	-22	7.2	45	113.0	66	150	302	393	740	1364	1232	2250	4082
-29	-20	-4	7.8	46	114.8	71	160	320	399	750	1382	1260	2300	4172
-23	-10	14	8.3	47	116.6	77	170	338	404	760	1400	1288	2350	4262
-17.8	0	32	8.9	48	118.4	82	180	356	410	770	1418	1316	2400	4352
			9.4	49	120.2	88	190	374	416	780	1436	1343	2450	4442
			10.0	50	122.0	93	200	392	421	790	1454	1371	2500	4532
			10.6	51	123.8	99	210	410	427	800	1472	1399	2550	4622
			11.1	52	125.6	100	212	413.6	432	810	1490	1427	2600	4712
			11.7	53	127.4	104	220	428	438	820	1508	1454	2650	4802
			12.2	54	129.2	110	230	446	443	830	1526	1482	2700	4892
			12.8	55	131.0	116	240	464	449	840	1544	1510	2750	4982
			13.3	56	132.8	121	250	482	454	850	1562	1538	2800	5072
			13.9	57	134.6	127	260	500	460	860	1580	1566	2850	5162
			14.4	58	136.4	132	270	518	466	870	1598	1593	2900	5252
			15.0	59	138.2	138	280	536	471	880	1616	1621	2950	5342
			15.6	60	140.0	143	290	554	477	890	1634	1649	3000	5432

(1) Locate temperature in middle column. If in degrees Celsius, read Fahrenheit equivalent in right hand column; if in degrees Fahrenheit, read Celsius equivalent in left hand column.

Table 8.2.2 Pressure Conversion[1]

from/to	PSI	KPA	Inches[2] H_2O	mmH_2O	Inches[3] Hg	mm Hg	Bars	m Bars	Kg/cm^2	gm/cm^2
PSI	1	6.8948	27.7620	705.1500	2.0360	51.7149	0.0689	68.9470	0.0703	70.3070
KPA	0.1450	1	4.0266	102.2742	0.2953	7.5006	0.0100	10.0000	0.0102	10.197
inH_2O*	0.0361	0.2483	1	25.4210	0.0734	1.8650	0.0025	2.4864	0.0025	2.5355
mmH_2O	0.0014	0.0098	0.0394	1	0.0028	0.0734	0.0001	0.0979	0.00001	0.0982
inHg**	0.4912	3.3867	13.6195	345.936	1	25.4000	0.0339	33.8639	0.0345	34.532
mm Hg	0.0193	0.1331	0.5362	13.6195	0.0394	1	0.0013	1.3332	0.0014	1.3595
Bars	14.5040	100.000	402.180	10215.0	29.5300	750.060	1	1000	1.0197	1019.72
m Bars	0.0145	0.1000	0.4022	10.2150	0.0295	0.7501	0.001	1	0.0010	1.0197
Kg/cm^2	14.2233	97.9047	394.408	10018.0	28.9590	735.559	0.9000	980.700	1	1000
gm/cm^2	0.0142	0.0979	0.3944	10.0180	0.0290	0.7356	0.0009	0.9807	0.001	1

(1) EXAMPLE
1 mm Hg = 0.5362 inH_2O = 1.3332 mBars
97 mm Hg = 97(0.5362) = 52.0114 inH_2O
97 mm Hg = 97(1.332) = 129.3204 mBars
(2) at 60 °F
(3) at 32 °F

Table 8.2.3 Volume Conversion[1]

from\to	cm^3	liter	m^3	in^3	ft^3	yd^3	fl oz	fl pt	fl qt	gal	gal(Imp.)	bbl(oil)	bbl(liq)
cm^3	1	0.001	1×10^{-6}	0.06102	3.53×10^{-5}	1.31×10^{-4}	0.03381	0.00211	0.00106	2.64×10^{-4}	2.20×10^{-4}	6.29×10^{-6}	8.39×10^{-6}
liter	1000	1	0.001	61.02	0.03532	0.00131	33.81	2.113	1.057	0.2642	0.2200	0.00629	0.00839
m^3	1×10^{6}	1000	1	6.10×10^{4}	35.31	1.308	3.38×10^{4}	2113	1057	264.2	220.0	6.290	8.386
in^3	16.39	0.01639	1.64×10^{-5}	1	5.79×10^{-4}	2.14×10^{-5}	0.5541	0.03463	0.01732	0.00433	0.00360	1.03×10^{-4}	1.37×10^{-4}
ft^3	2.83×10^{4}	28.32	0.02832	1728	1	0.03704	957.5	59.84	29.92	7.481	6.229	0.1781	0.2375
yd^3	7.65×10^{5}	764.5	0.7646	4.67×10^{4}	27	1	2.59×10^{4}	1616	807.9	202.0	168.2	4.809	6.412
fl oz	29.57	0.02957	2.96×10^{-6}	1.805	0.00104	3.87×10^{-5}	1	0.06250	0.03125	0.00781	0.00651	1.86×10^{-4}	2.48×10^{-4}
fl pt	473.2	0.4732	4.73×10^{-4}	28.88	0.01671	6.19×10^{-4}	16	1	0.5000	0.1250	0.1041	0.00298	0.00397
fl qt	946.4	0.0463	9.46×10^{-4}	57.75	0.03342	0.00124	32	2	1	0.2500	0.2082	0.00595	0.00794
gal	3785	3.785	0.00379	231.0	0.1337	0.00495	128	8	4	1	0.8327	0.02381	0.03175
gal(Imp)	4546	4.546	0.00455	277.4	0.1605	0.00595	153.7	9.608	4.804	1.201	1	0.02859	0.03813
bbl(oil)	1.59×10^{5}	159.0	0.1590	9702	5.615	0.2079	5376	336	168	42	34.97	1	1.333

(1) 1 cord = 128 ft^3 = 3.625 m^3

Table 8.2.4 Flow Rate Conversion[1]

from\to	lit/sec	gal/min	ft^3/sec	ft^3/min	bbl/hr	bbl/day
lit/sec	1	15.85	0.03532	2.119	22.66	543.8
gal/min	0.06309	1	0.00223	0.1337	1.429	34.30
ft^3/sec	28.32	448.8	1	60	641.1	1.54×10^{4}
ft^3/min	0.4719	7.481	0.01667	1	10.69	256.5
bbl/hr	0.04415	0.6997	0.00156	0.09359	1	24
bbl/day	0.00184	0.02917	6.50×10^{-5}	0.00390	0.04167	1

(1) bbl refers to bbl oil = 42 gallons

Table 8.2.5 Equivalents

Linear Measure		Measure of Volume	
1 micron	0.000001 meter	1 cu centimeter	0.061 cu in.
1 mm	0.03937 in.	1 cu inch	16.39 cu cm
1mm	0.00328 ft	1 cu decimeter	0.0353 cu ft
1 centimeter	0.3937 in.	1 cu foot	28.317 cu decimeters
1 inch	2.54 centimeters	1 cu yard	0.7646 cu meters
1 inch	25.4 mm	1 stere	0.2759 cord
1 decimeter	3.937 in.	1 cord	3.264 steres
1 decimeter	0.328 foot	1 liter	0.908 qt dry
1 foot	3.048 decimeters	1 liter	1.0567 qts liq
1 foot	30.48 cm	1 quart dry	1.101 liters
1 foot	304.8 mm	1 quart liquid	0.9463 liters
1 meter	39.37 in.	1 dekaliter	2.6417 gals
1 meter	1.0936 yds	1 dekaliter	1.135 pecks
1 yard	0.9144 meter	1 gallon	0.3785 dekaliter
1 dekameter	1.9884 rods	1 peck	0.881 dekaliter
1 rod	0.5029 dekameter	1 hectoliter	2.8375 bushels
1 kilometer	0.62137 mile	1 bushel	0.3524 hectoliter
1 mile	1.6093 kilometers		
Square Measure		**Weights**	
1 sq centimeter	0.1550 sq in.	1 gram	0.03527 ounce
1 sq centimeter	0.00108 sq ft	1 ounce	28.35 grams
1 sq inch	6.4516 sq centimeters	1 kilogram	2.2046 pounds
1 sq decimeter	0.1076 sq ft	1 pound	0.4536 kilogram
1 sq ft	929.03 sq cm	1 metric ton	0.98421 English ton
1 sq ft	9.2903 sq dec	1 English ton	1.016 metric ton
1 sq meter	1.196 sq yds	1 kg	2.205 pounds
1 sq yard	0.8361 sq meter	1 cu in. of water (60 °F)	0.073551 cu in. of mercury (32 °F)
1 acre	160 sq rods	1 cu in. of mercury (32 °F)	13.596 cu in. of water (60 °F)
1 sq rod	0.00625 acre	1 cu in. of mercury (32 °F)	0.4905 pounds
1 hectare	2.47 acres		
1 acre	0.4047 hectare		
1 sq kilometer	0.386 sq mile		
1 sq mile	2.59 sq kilometers		
Circumference of a circle	$2\pi r$		
Circumference of a circle	πd		
Area of a circle	πr^2		
Area of a circle	$\pi d^2/4$		
		Velocity	
		1 ft/sec	0.3048 m/sec
		1 m/sec	3.2808 ft/sec
		Density	
		1 lb/cu in	27.68 gram/cu cm
		1 gr/cu cm	0.03613 lb/cu in.
		1 lb/cu ft	16.0184 kg/cu m
		1 kg/cu m	0.06243 lb/cu ft

Table 8.2.6 English to Metric System Conversion

1 To Convert from:	2 To:	3 Multiply by:	To Convert Column 2 to Column 1 Multiply by:
acre-feet	cubic meters	1233	8.11×10^{-4}
cubic feet (cu ft) (US)	cubic centimeters	28,317	3.53×10^{-5}
cubic feet (cu ft) (US)	cubic meters	0.0283	35.33
cubic feet (cu ft) (US)	liters	28.32	0.035
cu ft/min	cu cm/sec	472	0.0021
cu ft/min	liters/sec	0.472	2.119
cu ft/sec	liters/min	1699	5.886×10^{-4}
cubic inches (US)	cubic meters	1.64×10^{-5}	61,024
cubic inches (US)	liters	0.0164	61.024
cubic inches (US)	milliliters (ml)	16.387	0.0610
feet (US)	meters	0.3048	3.281
feet (US)	millimeters (mm)	304.8	3.28×10^{-3}
feet/min	cm/sec	0.508	1.97
feet/min	kilometers/hr	1.829×10^{-2}	54.68
feet/min	meters/min	0.305	3.28
ft/sec^2	km/hr/sec	1.0973	0.911
gallons (US)	cu cm (ml)	3785	2.64×10^{-4}
gallons (US)	liters	3.785	0.264
gallons/min	liters/sec	0.063	15.87
US gal/min	cu meters/hr	0.227	4.4
US gal/sq ft/min	cu meters/hr/sq meters	2.45	0.408
grains (troy)	grams	0.0648	15.432
grains (troy)	milligrams (mg)	64.8	0.01543
grains/gal (US)	grams/liter	0.0171	58.417
grains/gal (US)	ppm	17.1	0.0584
inches (US)	centimeters (cm)	2.54	0.3937
inches (US)	millimeters (mm)	25.4	0.0394
miles (US)	kilometers (km)	1.609	0.6215
miles (US)	meters	1609	6.214×10^{-4}
miles/hr	cm/sec	44.7	0.0224
miles/hr	meters/min	26.82	0.0373
miles/min	kilometers/hr	96.6	1.03×10^{-2}
ounces (avoirdupois)	grams	28.35	0.0353
ounces (US fluid)	ml	29.6	0.0338
ounces (US fluid)	liters	0.0296	33.81
pounds (av)	grams	453.6	0.0022
pounds (av)/sq in	kgr/cm^2	0.071	14.223
pounds (av)	kilograms	0.4536	2.205
pounds (av)	grains	7000	14.2×10^{-5}
pounds/cu ft	grams/l	16.02	0.0624
pounds/ft	grams/cm	14.88	0.067
pounds/gal (US)	grams/ml	0.12	8.345
pounds/gal (US)	grams/liter	119.8	8.34×10^{-3}
quart (US liq)	ml	946.4	0.001057
quart (US liq)	liters	0.946	1.057
square feet (US)	sq cm	929	1.08×10^{-3}
square feet (US)	sq meters	0.0929	10.76
square inches (US)	sq cm	6.452	0.155

Table 8.2.7 Decimal Equivalents

8ths	16ths	32nds	64ths	
1/8 = 0.125	1/16 = 0.0625	1/32 = 0.03125	1/64 = 0.015625	33/64 = 0.515625
1/4 = 0.250	3/16 = 0.1875	3/32 = 0.09375	3/64 = 0.046875	35/64 = 0.546875
3/8 = 0.375	5/16 = 0.3125	5/32 = 0.15625	5/64 = 0.078125	37/64 = 0.578125
1/2 = 0.500	7/16 = 0.4375	7/32 = 0.21875	7/64 = 0.109375	39/64 = 0.609375
5/8 = 0.625	9/16 = 0.5625	9/32 = 0.28125	9/64 = 0.140625	41/64 = 0.640625
3/4 = 0.750	11/16 = 0.6875	11/32 = 0.34375	11/64 = 0.171875	43/64 = 0.671875
7/8 = 0.875	13/16 = 0.8125	13/32 = 0.40625	13/64 = 0.203125	45/64 = 0.703125
	15/16 = 0.9375	15/32 = 0.46875	15/64 = 0.234375	47/64 = 0.734375
		17/32 = 0.53125	17/64 = 0.265625	49/64 = 0.765625
		19/32 = 0.59375	19/64 = 0.296875	51/64 = 0.796875
		21/32 = 0.65625	21/64 = 0.328125	53/64 = 0.828125
		23/32 = 0.71875	23/64 = 0.359375	55/64 = 0.859375
		25/32 = 0.78125	25/64 = 0.390625	57/64 = 0.890625
		27/32 = 0.84375	27/32 = 0.421875	59/64 = 0.921875
		29/32 = 0.90625	29/32 = 0.453125	61/64 = 0.953125
		31/32 = 0.96875	31/64 = 0.484375	63/64 = 0.984375

Table 8.2.8 Multiplication Factors

Prefix	Symbol	Name	Multiplication Factor	
atto	a	one-quintillionth	0.000 000 000 000 000 001	10^{-18}
femto	f	one-quadrillionth	0.000 000 000 000 001	10^{-15}
pico	p	one-trillionth	0.000 000 000 001	10^{-12}
nano	n	one-billionth	0.000 000 001	10^{-9}
micro	m	one-millionth	0.000 001	10^{-6}
milli	m	one-thousandth	0.001	10^{-3}
centi	c	one-hundreth	0.01	10^{-2}
deci	d	one-tenth	0.1	10^{-1}
uni		one	1.0	10^{0}
deka	da	ten	10.0	10^{1}
hecto	h	one hundred	100.0	10^{2}
kilo	k	one thousand	1 000.0	10^{3}
mega	M	one million	1 000 000.0	10^{6}
giga	G	one billion	1 000 000 000.0	10^{9}
tera	T	one trillion	1 000 000 000 000.0	10^{12}

Table 8.2.9 Saturated Steam Table v1

Pressure inches Hg at 32 °F	Absolute Pressure Lbs./Sq. In.	Temperature °F	Cu. Ft./Lb. Sat. Vapor	TOTAL HEAT IN B.T.U. PER LB.		
				Sat. Liquid	Evap.	Sat. Vapor
1.02	0.5	80	642	47.60	1047.5	1095.1
2.03	1	101	334	69.69	1035.3	1105.0
4.06	2	126	174	93.97	1021.6	1115.6
6.09	3	142	119	109.33	1012.7	1120.0
10.15	5	162	74.0	130.10	1000.4	1130.6
15.3	7.5	180	50.3	147.81	989.9	1137.7
20.3	10	193	38.4	161.13	981.8	1143.0
28.5	14	209	28.0	177.55	971.8	1149.3
29.92	14.696	212	26.8	180.00	970.2	1150.2

Table 8.2.10 Saturated Steam Table v2

Gage Pressure Lbs. \ Sq. Inch	Absolute Pressure Lbs./Sq. In.	Temperature °F	Cu. Ft./Lb. Sat. Vapor	TOTAL HEAT IN B.T.U. PER LB. Sat. Liquid	Evap.	Sat. Vapor
0.0	14.696	212	26.8	180.0	970.2	1150.2
1.3	16	216	24.8	184.35	967.4	1151.8
2.3	17	219	23.4	187.48	965.4	1152.9
3.3	18	222	22.2	190.48	963.5	1154.0
4.3	19	225	21.1	193.34	961.7	1155.0
5.3	20	228	20.1	196.09	959.9	1156.0
7.3	22	233	18.4	201.25	956.6	1157.8
10.3	25	240	16.3	208.33	951.9	1160.2
15.3	30	250	13.7	218.73	945.0	1163.7
20.3	35	259	11.9	227.82	938.9	1166.7
25.3	40	267	10.5	235.93	933.3	1169.2
30.3	45	274	9.40	243.28	928.2	1171.5
35.3	50	281	8.51	249.98	923.5	1173.5
40.3	55	287	7.78	256.19	919.1	1175.3
45.3	60	293	7.17	261.98	915.0	1177.0
50.3	65	298	6.65	267.39	911.1	1178.5
55.3	70	303	6.20	272.49	907.4	1179.9
60.3	75	307	5.81	277.32	903.9	1181.2
65.3	80	312	5.47	281.90	900.5	1182.4
70.3	85	316	5.16	286.90	897.3	1183.6
75.3	90	320	4.89	290.45	894.2	1184.6
80.3	95	324	4.65	294.47	891.2	1185.6
85.3	100	328	4.42	298.33	888.2	1186.6
90.3	105	331	4.22	302.03	885.4	1187.5
95.3	110	335	4.04	305.61	882.7	1188.3
100.3	115	338	3.88	309.04	880.0	1189.1
105.3	120	341	3.72	312.37	877.4	1189.8
110.3	125	344	3.60	315.60	874.9	1190.5
115.3	130	347	3.45	318.73	872.4	1191.2
120.3	135	350	3.33	321.77	870.0	1191.8
125.3	140	353	3.22	324.74	867.7	1192.4
130.3	145	356	3.20	327.63	865.3	1193.0
135.3	150	358	3.01	330.44	863.1	1193.5
140.3	155	361	2.92	333.18	860.8	1194.0
145.3	160	363	2.83	335.86	858.7	1194.5
150.3	165	366	2.75	338.47	856.5	1195.0
155.3	170	368	2.67	341.03	854.5	1195.4
160.3	175	370	2.60	343.54	852.3	1195.9
165.3	180	373	2.53	345.99	850.3	1196.3
170.3	185	375	2.46	348.42	848.2	1196.7
175.3	190	377	2.40	350.77	846.3	1197.0
180.3	195	380	2.34	353.07	844.3	1197.4
185.3	200	382	2.28	355.33	842.4	1197.8
210.3	225	392	2.039	366.10	833.2	1199.3
235.3	250	401	1.841	376.02	824.5	1200.5
260.3	275	409	1.678	385.24	816.3	1201.6
285.3	300	417	1.541	393.90	808.5	1202.4
335.3	350	432	1.324	409.81	793.7	1203.6
385.3	400	444	1.160	424.2	779.8	1204.1
435.3	450	456	1.030	437.4	766.7	1204.1
485.3	500	467	0.926	449.7	754.0	1203.7
585.3	600	486	0.767	472.3	729.8	1202.1
685.3	700	503	0.653	492.9	706.8	1199.7
785.3	800	518	0.565	511.8	684.9	1196.7

Table 8.2.10 cont. Saturated Steam Table v2

Gage Pressure Lbs. \ Sq. Inch	Absolute Pressure Lbs./Sq. In.	Temperature °F	Cu. Ft./Lb. Sat. Vapor	TOTAL HEAT IN B.T.U. PER LB. Sat. Liquid	Evap.	Sat. Vapor
885.3	900	532	0.496	529.5	663.8	1193.3
985.3	1000	544	0.442	546.0	643.5	1189.6
1235.3	1250	572	0.341	583.6	595.6	1179.2
1485.3	1500	596	0.274	617.5	550.2	1167.6
1985.3	2000	635	0.187	679.0	460.0	1139.0
2485.3	2500	668	0.130	742.8	352.8	1095.6
2985.3	3000	695	0.084	823.1	202.5	1025.6
3211.3	3226	706	0.0522	925.0	0	925.0

Table 8.2.11 Maximum Permissible ID and Minimum Wall in Accordance with ASTM A106 Pipe(1)

Nominal Pipe Size	Outside Diam. Max.	Wall I.D.	Schedule 10	Schedule 20	Schedule 30	Standard Weight	Schedule 40	Schedule 60	Extra Strong	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160	Dbl. Ext. Strong
1/8	0.421	Wall				0.060	0.060		0.083	0.083					
		I.D.				0.302	0.302		0.254	0.254					
1/4	0.556	Wall				0.077	0.077		0.110	0.110					
		I.D.				0.402	0.402		0.335	0.335					
3/8	0.691	Wall				0.080	0.080		0.110	0.110					
		I.D.				0.531	0.531		0.470	0.470					
1/2	0.856	Wall				0.095	0.095		0.129	0.129				0.164	0.257
		I.D.				0.665	0.665		0.598	0.598				0.528	0.341
3/4	1.066	Wall				0.099	0.099		0.135	0.135				0.191	0.270
		I.D.				0.868	0.868		0.796	0.796				0.684	0.527
1	1.331	Wall				0.116	0.116		0.157	0.157				0.219	0.313
		I.D.				1.098	1.098		1.017	1.017				0.893	0.704
1 1/4	1.676	Wall				0.123	0.123		0.167	0.167				0.219	0.334
		I.D.				1.431	1.431		1.341	1.341				1.238	1.007
1 1/2	1.916	Wall				0.127	0.127		0.175	0.175				0.246	0.350
		I.D.				1.662	1.662		1.566	1.566				1.424	1.216
2	2.406	Wall				0.135	0.135		0.191	0.191				0.300	0.382
		I.D.				2.137	2.137		2.025	2.025				1.806	1.643
2 1/2	2.906	Wall				0.178	0.178		0.242	0.242				0.328	0.483
		I.D.				2.551	2.551		2.423	2.423				2.250	1.940
3	3.531	Wall				0.189	0.189		0.263	0.263				0.383	0.525
		I.D.				3.153	3.153		3.006	3.006				2.765	2.481
3 1/2	4.031	Wall				0.198	0.198		0.278	0.278					0.557
		I.D.				3.636	0.3636		3.475	0.3475					2.918
4	4.531	Wall				0.207	0.207		0.295	0.295		0.383		0.465	0.590
		I.D.				4.117	4.117		3.942	3.942		3.765		3.602	3.352
5	5.626	Wall				0.226	0.226		0.328	0.328		0.438		0.547	0.656
		I.D.				5.174	5.174		4.969	4.969		4.751		4.532	4.313
6	6.688	Wall				0.245	0.245		0.378	0.378		0.492		0.628	0.756
		I.D.				6.198	6.198		5.932	5.932		5.704		5.431	5.176
8		Wall		0.219	0.242	0.282	0.282	0.355	0.438	0.438	0.519	0.628	0.711	0.793	0.766
		I.D.		8.250	8.203	8.124	8.124	7.977	7.813	7.813	7.650	7.431	7.267	7.102	7.156
10	10.84	Wall		0.219	0.269	0.319	0.319	0.438	0.438	0.519	0.628	0.738	0.875	0.984	
	4	I.D.		10.406	10.307	10.205	10.205	9.969	9.969	9.806	9.587	9.369	9.094	8.875	
12	12.84	Wall		0.219	0.289	0.328	0.355	0.492	0.438	0.601	0.738	0.875	0.984	1.148	
	4	I.D.		12.406	12.266	12.188	12.133	11.860	11.969	11.642	11.369	11.094	10.875	10.548	
14	14.09	Wall	0.219	0.273	0.328	0.328	0.383	0.519	0.438	0.656	0.820	0.956	1.094	1.230	
	4	I.D.	13.656	13.548	13.438	13.438	13.327	13.056	13.219	12.781	12.454	12.181	11.906	11.633	
16	16.09	Wall	0.219	0.273	0.328	0.328	0.438	0.574	0.438	0.738	0.902	1.066	1.258	1.394	
	4	I.D.	15.656	15.548	15.438	15.438	15.219	14.946	15.219	14.619	14.290	13.962	13.577	13.306	
18	18.09	Wall	0.219	0.273	0.383	0.328	0.492	0.656	0.438	0.820	1.012	1.203	1.367	1.558	
	4	I.D.	17.656	17.548	17.327	17.438	17.110	16.781	17.219	16.454	16.071	15.688	15.360	14.977	
20	20.12	Wall	0.219	0.328	0.438	0.328	0.519	0.711	0.438	0.902	1.121	1.313	1.531	1.722	
	5	I.D.	19.688	19.469	19.250	19.469	19.087	18.704	19.250	18.321	17.883	17.500	17.063	16.681	
24	24.12	Wall	0.219	0.328	0.492	0.328	0.601	0.847	0.438	1.066	1.340	1.586	1.804	2.050	
	5	I.D.	23.688	23.469	23.142	23.469	22.923	22.431	23.250	21.994	21.446	20.954	20.517	20.025	
30	30.12	Wall	0.273	0.438	0.547	0.328			0.438						
	5	I.D.	29.579	29.250	29.031	29.469			29.250						

(1) O.D.—MAX. I.D.—MAX. WALL—MIN.

Table 8.2.12 Dimensions of Welded and Seamless Pipe Carbon and Alloy Steel

Nominal Pipe Size	Outside Diameter	Wall Thickness Inside Diameter	Nominal Wall Thickness And Inside Diameter			
			Schedule 5S*	Schedule 10S*	Schedule 40S	Schedule 80S
1/8	0.405	Wall	–	0.049	0.068	0.095
		I.D.	–	0.307	0.269	0.215
1/4	0.540	Wall	–	0.065	0.088	0.119
		I.D.	–	0.410	0.364	0.302
3/8	0.675	Wall	–	0.065	0.091	0.126
		I.D.	–	0.545	0.493	0.423
1/2	0.840	Wall	0.065	0.083	0.109	0.147
		I.D.	0.710	0.674	0.622	0.546
3/4	1.050	Wall	0.065	0.083	0.113	0.154
		I.D.	0.920	0.884	0.824	0.742
1	1.315	Wall	0.065	0.109	0.133	0.179
		I.D.	1.185	1.097	1.049	0.957
1 1/4	1.660	Wall	0.065	0.109	0.140	0.191
		I.D.	1.530	1.442	1.380	1.278
1 1/2	1.900	Wall	0.065	0.109	0.145	0.200
		I.D.	1.770	1.682	1.610	1.500
2	2.375	Wall	0.065	0.109	0.154	0.218
		I.D.	2.245	2.157	2.067	1.939
2 1/2	2.875	Wall	0.083	0.120	0.203	0.276
		I.D.	2.709	2.635	2.469	2.323
3	3.500	Wall	0.083	0.120	0.216	0.300
		I.D.	3.334	3.260	3.068	2.900
3 1/2	4.000	Wall	0.083	0.120	0.226	0.318
		I.D.	3.834	3.760	3.548	3.364
4	4.500	Wall	0.083	0.120	0.237	0.337
		I.D.	4.334	4.260	4.026	3.826
5	5.563	Wall	0.109	0.134	0.258	0.375
		I.D.	5.345	5.295	5.047	4.813
6	6.625	Wall	0.109	0.134	0.280	0.432
		I.D.	6.407	6.357	6.065	5.761
8	8.625	Wall	0.109	0.148	0.322	0.500
		I.D.	8.407	8.329	7.981	7.625
10	10.750	Wall	0.134	0.165	0.365	0.500**
		I.D.	10.482	10.420	10.020	9.750**
12	12.750	Wall	0.156	0.180	0.375**	0.500**
		I.D.	12.438	12.390	12.000**	11.750**
14†	14.000	Wall	0.156	0.188	–	–
		I.D.	13.688	13.624	–	–
16†	16.000	Wall	0.165	0.188	–	–
		I.D.	15.670	15.624	–	–
18†	18.000	Wall	0.165	0.188	–	–
		I.D.	17.670	17.624	–	–
20†	20.000	Wall	0.188	0.218	–	–
		I.D.	19.624	19.564	–	–
24†	24.000	Wall	0.218	0.250	–	–
		I.D.	23.564	23.500	–	–
30†	30.000	Wall	0.250	0.312	–	–
		I.D.	29.500	29.376	–	–

NOTE

All dimensions given for inches. The wall thicknesses shown represent nominal or average wall dimensions which are subject to 12.5% mill tolerance.

†Sizes 14” through 30” show dimensions commonly used in the industry.

*Schedule 5S and 10S wall thicknesses do not permit threading in accordance with ASA B2.1.

**Schedule 40S and schedule 80S in these sizes do not agree with schedule 40 and schedule 80 of ASA B36.10 and that they are identical to standard weight and extra strong respectively of ASA B36.10.

8.3 – Safety Instrumented Systems (SIS)

Introduction

There is a rapidly growing trend in the process industry to ensure that industrial plants are operated in a safe manner. Internationally endorsed safety standards have been developed and widely adopted that provide guidance for protecting a company's employees, its capital investments and the environment. Plant owners and system integrators follow the IEC 61511 standard which is endorsed by ISA and OSHA for reasons that include legalistic, humanistic, moral or economic. Most companies have or hire trained safety-certified engineers to analyze risk for various operating units and design, specify and implement Safety Instrumented Systems (SIS) to reduce the risk to what is considered to be a tolerable level by the owner. Hazardous risks that must be mitigated typically include flammable materials, toxic materials, high pressures and high temperatures.

The new standards are performance-based, rather than prescriptive. They require you to set performance levels, or goals, to be achieved by SIS engineering design, rather than prescribing what that design should look like. The amount of risk reduction required to meet safety goals guides the system design process. There is considerable very specialized engineering involved in this design process that requires highly skilled and certified safety engineers. The standard comprises a 12 step safety lifecycle that covers the entire life of the SIS form conceptual design through to decommissioning.

Definitions

Safety Instrumented System (SIS) is defined by the IEC 61511 Safety Standard as an instrumented system used to implement one or more safety instrumented functions. An SIS is composed of any combination of sensors, logic solvers, and final elements.

It is designed for the purpose of:

- Automatically *taking an industrial process to a safe state* when specified conditions are violated

  – "Preventative"

- Permit a process to move forward in a safe manner when specified conditions allow (permissive functions) or

  – "Permissive"

- Taking action to mitigate the consequences of an industrial hazard

  – "Mitigative"

The SIS may be thought of as the last line of defense against a hazardous condition and is separate and independent from the Basic Process Control System (BPCS).

For example, a reactor vessel may have a temperature measurement that is used as the process variable for a control loop. If this temperature is not properly controlled, it could reach a dangerous point and cause an explosion. Accordingly, as a safety related measurement, the system would have an independent temperature measurement from the BPCS measurement for the purpose of independently detecting this potentially dangerous condition, comparing it against a pre-defined safe value, and taking the appropriate action to arrest or contain the situation should this value be exceeded.

The standard uses the word ***"sensor"*** to describe any field measurement system and is typically a sensor/transmitter assembly in the case of temperature measurement.

A ***Logic Solver*** is the term given to the safety certified controller that implements the required logic. It may be as simple as a single channel safety-certified alarm trip module or as complex as a quad-redundant PLC system.

A ***Final Control Element*** is most often a safety shutoff valve but could also be a VFD, a relief valve, a fire suppression system or a motor starter.

A ***Safety Instrumented Function (SIF)*** is defined as a function to be implemented by a SIS which is intended to achieve or maintain a safe state for the process with respect to a specific hazardous event.

A SIF is a single set of actions and the corresponding equipment needed to identify a single hazard and act to bring the system to a safe state. While it is possible for a SIS to have only one SIF, more commonly a SIS will encompass multiple functions and act in multiple ways to prevent multiple harmful outcomes. One SIS often has multiple SIF's each with a different individual Safety Integrity Level (SIL).

Safety Integrity Levels (SIL)– as defined in part 4 of the IEC 61508 standard, is “the likelihood of a safety-related system satisfactorily performing the safety functions under all the stated conditions, within a period of time”. A safety integrity level is further defined as “a discrete level (one of four) for specifying the safety integrity requirements of safety functions.”

Safety integrity levels (SILs) are derived from the assessment of risks, although they are not a measure of risk. They are a measure of the required reliability of a system or function. They relate to the target reliability of dangerous failures of the system in question. In general, the greater the required risk reduction, the more reliable the safety-related system, which means the higher the SIL level. SIL levels range from SIL 1 to SIL 4. In the process control industry the vast majority of SIFs are SIL 1 with a much smaller requirement for SIL 2 and an even smaller need for SIL 3. SIL 4 is virtually unheard of in the process industries.

Note: A Safety Integrity Level (SIL) is selected for each Safety Instrumented Function (SIF). It is incorrect and ambiguous to define a SIL for an entire SIS or for any particular device.

Safety Requirements Specification (SRS)– Per IEC 61511 it is a specification that contains all the requirements of the safety functions that must be performed by the safety instrumented system. Its objective per IEC 61511 is to specify all of the requirements of safety instrumented systems needed for detailed engineering and process safety information purposes.

Compliance

A device (a temperature transmitter for example) that is a component of a SIF must meet several criteria to be in ***compliance*** with the IEC 61511 safety standard.

- It must be ***certified*** for use in a SIS up to the SIL level required for the SIF.
  - An example of a Rosemount specification:
    - “Certification: The 3144P is certified to IEC61508 for single transmitter use in Safety Instrumented Systems up to SIL 2 and redundant transmitter use in Safety Instrumented Systems up to SIL 3. The software is suitable for SIL 3 application.”
- It must be installed in accordance with the Safety Requirements Specification (SRS) that covers the particular SIF.
- It must be tested and maintained in accordance with the test plan established for the SIS.
- It will be included in the Management of Change (MOC) guidelines and procedures for the SIS which includes complete documentation of any changes made to the SIF. Examples may include any changes to the hardware or software like sensor or transmitter replacement / upgrade or a range change.

Selecting SIS Devices

There are two paths to follow for selecting a suitable device for use in a SIS: Certification and Proven-In-Use (PIU).

Certification:
Includes consideration of–

- Hardware
  - Hardware considerations are accomplished using a Failure Modes, Effects, and Diagnostic Analysis (FMEDA). An independent third party generally evaluates the schematics and hardware of a product, along with its diagnostic capabilities, in order to consider the failure modes, which include safe detected, safe undetected, dangerous detected, and dangerous undetected. In every case, a probability of failure on demand (PFD) is provided. The PFD is the probability that the loop/device will be in a failure mode when demand is placed on the system.
- Software
- Performed by an authorized third party testing facility (TUV for example)
- Certified Manufacturing Capabilities
  - Use of Proper Design Tools
  - A certified QA procedure
  - Tracking of modifications (Rev numbers)
- Environmental Stress Testing
- Electromagnetic Compatibility
- Safety Manual

There will be a yellow Safety Tag on the outside of the transmitter.

Proven-In-Use (PIU)
As an alternative to using certified devices, a device that has not been certified but that has a long record of *proven-in-use* safe operation may be used in a SIS *at the user's discretion*. This option requires that the user have detailed failure data for a statistically valid sample of the same model device operating under similar operating conditions. Records must be provided showing the hours of operating usage, the operating environment, the type and frequency of failures. Vendor upgrades to new models may require restarting the time clock on the data. Use in safety related systems is at the owner's discretion.

Best practice indicates that designing a system around an IEC 61508 certified instrument avoids the laborious and expensive record keeping for proven-in-use devices. It should be noted that many vendors offer the same basic product for both process control and safety applications. There is benefit to using the same models as are used in the basic process control system (BPCS) to take advantage of the history of installation and operation knowledge that already exists at the facility as well as spare parts inventory.

A certified transmitter with a Safe Failure Fraction (SFF) of 90 or above allows using only a single transmitter to meet the SIL 2 requirements. However, a Safety Instrumented Function (SIF) is assigned a Safety Integrity Level SIL) during risk analysis. All of the components of the SIF are considered together in performing a SIL compliance calculation. The result is that, even though the transmitter is certified up to SIL 2 as a single device, the limitations of the sensor and the valve typically demand a redundant configuration to meet a SIL 2 requirement. Therefore, most safety engineers follow the path of using two transmitters to provide a layer of hardware redundancy for fault tolerance in a 1 out of 2 (1oo2) or 2 out of 2 (2oo2) configuration. Using "proven-in-use" transmitters would require redundancy just for the transmitter to meet SIL 2 requirements.

Installation

Although there are no special requirements for installation of a safety certified transmitter, it is especially important to follow installation best practices as discussed in Chapter 4 of this handbook and to precisely follow the Safety Requirements Specification (SRS) to ensure a reliable installation.

Additionally, since the sensor assembly and all of the interconnecting wiring are part of the safety function, due care should be exercised in ensuring that all connections are in accordance with the loop sheets, properly tagged, and that covers are properly installed.

Pre-Startup Acceptance Testing (PSAT)

During this phase the installation is inspected and tested to ensure that it is complete agreement with the Safety Requirements Specification (SRS) with respect to hardware, software, installation detail and configuration.

It is generally accepted that this testing should be done by a qualified independent third party who has a complete understanding of the SRS.

Any deviations must be documented and corrected before start-up may commence.

Maintenance

For any safety related device there will be a very detailed and precise test plan for the unit operation. The safety standard requires that all personnel involved with SIS should have the proper qualifications and training.

Note that transmitter output is not safety-rated during: configuration changes, multi-drop, and loop test. Alternative means should be used to ensure process safety during transmitter configuration, maintenance and testing activities.

To ensure compliance with the IEC 61511 safety standard, there are normally permissions and permits that must be completed to take a loop out of service and the testing procedure must be followed to the letter and often witnessed and signed and co-signed. Any abnormalities or failures must be carefully documented with multiple sign-off signatures. Any changes made to the loop must be incorporated into the Management of Change (MOC) documentation. These include any device replacement or upgrade and any configuration and calibration changes.

The test procedure will typically have steps to ensure that there is proper communication from the field transmitter to the DCS and that a proper signal is being received and that all alarm values are properly configured and operational.

The procedure will also include verification that the final control element properly functions in accordance with the Safety Requirements Specification (SRS).

Since the SIF also includes the sensor, its lead-wires, the signal wiring and any terminations, these also must all be tested and verified. The ultimate and ideal test is to subject the sensor in situ to a precisely known standard temperature such as a calibration block or bath which forces a simultaneous test of all components of the SIF. Since this is rarely practical in the real world, other simulation sources are typically used and the sensor and its circuitry independently tested and calibrated.

Management of Change (MOC)

Management of Change (MOC) is the process when any changes are proposed to the Safety Instrumented System, that are not like-in-kind changes. For example using a different model or supplier from that in the original design.

The Management of Change procedures for the facility should be followed to completely evaluate and consider the impact of those changes to identify any potential hazards that could result from those changes prior to implementation. This step is important to ensure that the modifications are consistent with the Safety Requirements Specification (SRS), and preserve the required Safety Integrity Levels.

Any new components used in the change are likely to affect the SIL verification calculations which should be repeated using the new device failure rate data.

9

Documentation

TOPIC PAGE

9.1 – White Papers

White Paper - Thermowell Calculations
00840-0200-2654, Rev AB
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Thermowell Calculations

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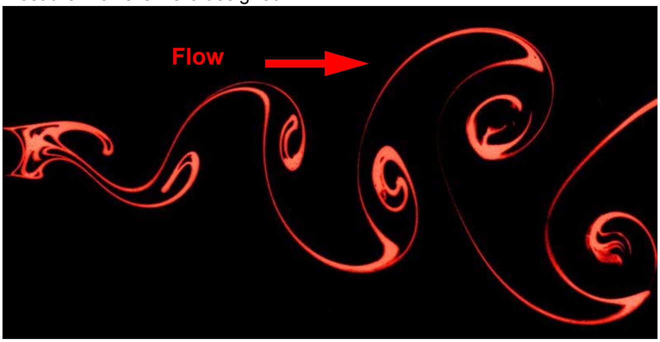
INTRODUCTION

Thermowells are essentially a circular cylinder installed like a cantilever into the process piping. They provide process condition protection and a process seal for temperature sensors. As a process fluid passes around the thermowell, low pressure vortices are created on the downstream side in laminar, turbulent, and transitional flow. The combination of stresses, generated by the static in-line drag forces from fluid flow and the dynamic transverse lift forces caused by the alternating vortex shedding, create the potential for fatigue-induced mechanical failures of the thermowell. Piping designers may use a variety of tools to predict and avoid thermowell failures in their systems, but ASME PTC 19.3-1974 had been the standard by which most thermowells were designed.



Color enhanced smoke trail showing von Karman Vortex Street in laminar fluid flow.[1]

BRIEF HISTORY OF ASME PTC 19.3

The standard dates back to 1957 when ASME (American Society of Mechanical Engineers) determined that the 1930's Supplement on Temperature Measurement was unsatisfactory because it did not include thermal and stress effects. ASME asked the Boiler and Pressure Vessel Committee to create a document, but it was deemed outside their scope. A stand-alone committee was then charged with all of temperature measurement with thermowell design as a section. The basis for ASME PTC 19.3-1974 was a paper authored by J.W. Murdock (1959).[2]

John Brock of the Naval Post Graduate School conducted some follow-on work in 1974 that uncovered several items that Murdock either assumed or ignored. Brock suggested such ideas as using a variable Strouhal Number rather than a fixed Strouhal Number, applying installation factors in the approximation of the natural frequency of the thermowell, and reviewing the frequency ratio limit of 0.8 to account for uncertainty in the natural frequency calculations[3]. Some of these demonstrated that there could be improvements made to ASME PTC 19.3-1974.

(1) Wikipedia http://en.wikipedia.org/wiki/Vortex_induced_vibration as of 5/20/2011
(2) Murdock, J.W., "Power Test Code Thermometer Wells" Journal of Engineering for Power (1959).
(3) Brock, John E., "Stress Analysis of Thermowells," Naval Postgraduate School, Monterey CA (1974).

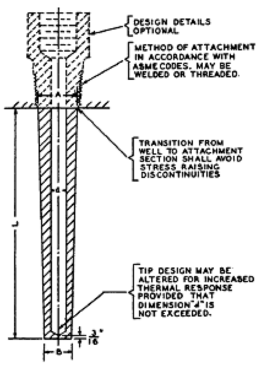
ASME PTC 19.3-1974 did not seem to account for all installations. An example of a high profile catastrophic thermowell fatigue failure came when the Monju (Japan) Fast Breeder reactor was shutdown due to a leak in a liquid sodium coolant system in 1995. The investigation revealed that the thermowell was designed in accordance to ASME PTC 19.3-1974 but the failure mode was due to the in-line resonance, which is not accounted for in the standard. The result was the development of the Japanese version of the standard, called JSME S012[(1)]. The reactor was eventually restarted in May of 2010 after years of investigation and legal battles.

For the most part, though, ASME PTC 19.3-1974 was used successfully in both steam and non-steam applications. Several key factors caused ASME to re-form the committee in 1999 to completely rewrite the standard; advances in the knowledge of thermowell behavior, a number of catastrophic failures (Monju among them) and the increased use of Finite Element Analysis for stress modeling. When combined, these factors caused many in the industry to move away from the rudimentary methods and simplified tables laid out in ASME PTC 19.3-1974 in favor of more advanced methods for predicting the thermowell natural frequency and calculating the forced frequency.

Rather than simply update the existing version of ASME PTC 19.3-1974, the committee decided to release a new standard due to the significant changes associated with the effort. The thermowell calculation portion of ASME PTC 19.3-1974 was 4 pages. By comparison, the new standard, known as ASME PTC 19.3 TW-2010 ("TW" for thermowell), is over 40 pages due to the explanations of theory and the sheer complexity of the process.

ASME PTC 19.3 TW-2010 was released in July 2010.

ASME PTC 19.3-1974 METHODOLOGY



As previously stated, the 1974 standard is very brief. It allows few stem profiles and uses simplified equations to model the thermowell for natural frequency calculations. Even though it allows any attachment method that is approved by the ASME Boiler and Pressure Vessel and Piping Codes, the equations do not differentiate between common mounting style variations such as flanged, threaded, and socket weld, and ignores the effects of different stem profiles, such as straight, taper, and stepped. Bore dimensions not in the tables are not accounted for, so bores for 1/4-in. and 6 mm diameter sensors share the same constants in the equations and no constants are provided for 3 mm diameter sensor bores.

For all its drawbacks, though, ASME PTC 19.3-1974 does have a simple process for thermowell evaluation that helped make it widely accepted in the industry; gather the process data and the thermowell materials information, calculate the natural and Strouhal Frequency, compare the ratio to 0.8, calculate the bending stress, compare maximum pressure to process pressure, and check the maximum length to the desired length.

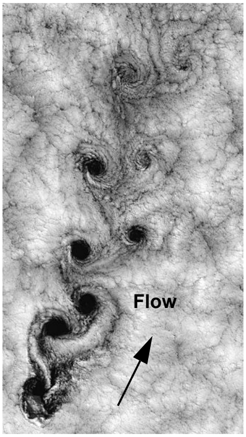
(1) Odahara, Sanoru, et al. "Fatigue Failure by In-line Flow-induced Vibration and Fatigue Life Evaluation," JSME International Journal, Series A, Vol. 48, No. 2 (2005).

Gathering the process data and materials information is a straightforward step except that there is one piece of data that is no longer readily available. The "Ratio of frequency at process temperature to frequency at 70 °F" is not easily found.

The method of calculating the thermowell natural frequency uses a simple equation, but some of the terms, such as K_f, are not well defined. If the thermowell U-length does not match one of those listed in the table, the designer should use the data for the length longer than the thermowell to be conservative. For an acceptable thermowell design, the ratio of the Strouhal frequency and the natural frequency "shall not exceed" 0.8.

The final step is an evaluation of the thermowell length based on the steady state stress. This determines the maximum length the thermowell can be in order to handle the bending stress. This length is compared to the desired length to determine if it is acceptable or if it must be shortened.

VORTEX SHEDDING THEORY (basis for ASME PTC 19.3 TW-2010)



Landsat 7 image of a von Karman Vortex Street in the clouds off the Chilean coast near the Juan Fernandez Islands (15 Sept 99). [1]

When a fluid flows around a blunt object in its path, vortices are formed downstream of the object. This is commonly referred to as vortex shedding, Von Karman Vortex Street, or flow vortices. The vortices are low pressure cells that are created and shed downstream in an alternating pattern. The differential pressure due to the alternating vortices produces alternating forces on the object. This results in alternating stresses on the object as it deflects. This phenomenon is observed in nature as eddies in the current downstream of bridge piers, swirls in the clouds downwind of the peaks of mountains, or Aeolian tones heard as the wind passes around utility lines. While vortex shedding is useful for process flow measurements, thermowell designers should avoid it due to the potential for failure.

(1) NASA Earth Observatory Website "http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=3328."

White Paper - Thermowell Calculations
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Thermowells

Because the major cause of thermowell failure is fatigue due to resonance, the designer needs to understand vortex shedding in order to avoid its effects and predict the vortex shedding frequency. Since vortex shedding occurs at frequencies anywhere from about 50Hz to 1500Hz, the thermowell can experience a large number of cycles in a short amount of time.

Example of a thermowell failure due to vortex induced vibration(1)

As the vortex shedding frequency, or Strouhal Frequency, approaches the thermowell natural frequency, the tip displacement and stresses are greatly magnified and the thermowell can fail due to the large amount of energy it must absorb. So, in addition to process conditions such as pressure, temperature, and corrosion, the designer must account for the high cycle fatigue strength for overall suitability in the application.

Minimum Velocity

For slow flowing process fluids, there is not enough energy transferred from the process fluid to the thermowell to cause fatigue failure. If the following conditions are met, there is no need to conduct frequency limit calculations as the risk of thermowell failure is negligible.

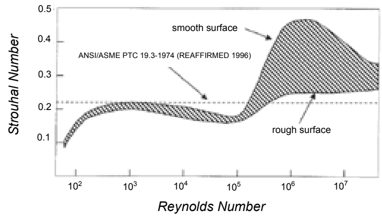
1. Process Fluid Velocity, $V < 0.64$ m/s (2.1 ft./sec)
2. Wall Thickness, $(A - d) \geq 9.55$ mm (0.376 in)
3. Unsupported Length, $L \leq 0.61$ m (24 in)
4. Root and Tip Diameter (A and B) $\geq$ 12.7 mm (0.5 in)
5. Maximum Allowable Stress, $S \geq 69$ Mpa (10 ksi)
6. Fatigue Endurance Limit, $S_f \geq 21$ Mpa (3 ksi)

Even so, these low velocities could still excite the in-line resonance and cause sensor failure due to the high vibration that exists at resonance. If these criteria are not met, or if there is a chance of stress corrosion or material embrittlement due to fluid interaction (which would cause a change to the fatigue endurance), the designer must fully evaluate the thermowell design.

Strouhal Number

There has been much discussion on the topic of whether to use a fixed or variable Strouhal Number. ASME PTC 19.3-1974 used a fixed Strouhal Number of 0.22 while Brock recommended a variable Strouhal Number depending on the Reynolds Number. Many in the industry began to incorporate the variable Strouhal Number to the vortex shedding frequency equations within the framework of ASME PTC 19.3-1974 calling it “the Brock Method” or something similar.

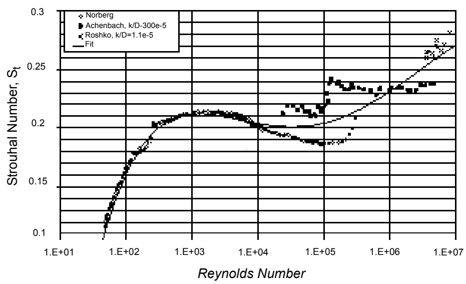
(1) Energy Institute, “Guidelines for the Avoidance of Vibration Induced Fatigue in Process Pipework” 2nd Edition, (2008), Publication Number 978-0-85293-463-0.



Typical chart showing Strouhal Number as a function of Reynolds Number

The ASME PTC 19.3 TW-2010 committee reviewed the subsequent experiments before deciding on how to use the variable Strouhal Number. Two papers published in the JSME International Journal in 2001 showed interesting test results for machined straight and tapered cylinders that were similar to thermowells in form. The forces and vibration amplitudes were measured while the cylinders were immersed in a fluid flow. The conclusion was that the evidence of a high Strouhal Number in previous experiments was based on measurements of the vortex shedding and not of the actual forces on the thermowell.(1) (2)

"Rough" surfaces were defined in the experiments as measuring in excess of 128 Ra. No thermowell in the process industry has a surface finish of more than 32 Ra and the stress limits and calculations in ASME PTC 19.3 TW-2010 are not valid for surface finishes rougher than 32 Ra.



Actual data of Strouhal Number of a rough cylinder as a function of Reynolds Number.(3)

Based on this data, the ASME PTC 19.3 TW-2010 committee decided to incorporate a variable Strouhal Number defined by the rough cylinder curve. To simplify calculations, the designers are also allowed to conservatively approximate the Strouhal Number as 0.22. This is especially useful if the designer cannot establish the dynamic or kinematic fluid viscosity to determine the Reynolds Number.

(1) Sakai, T., Iwata, K., Morishita, M., and Kitamura, S., "Vortex-Induced Vibration of a Circular Cylinder in Super-Critical Reynolds Number Flow and Its Suppression by Structure Damping," JSME Int. J. Ser. B. 44, 712-720 (2001).
(2) Iwata, K., Sakai, T., Morishita, M., and Kitamura, S., "Evaluation of Turbulence-Induced Vibration of a Circular Cylinder in Super-Critical Reynolds Number Flow and Its Suppression by Structure Damping," JSME Int. J. Ser. B. 44, 721-728 (2001).
(3) ASME Standard, Performance Test Codes 19.3TW (draft 7).

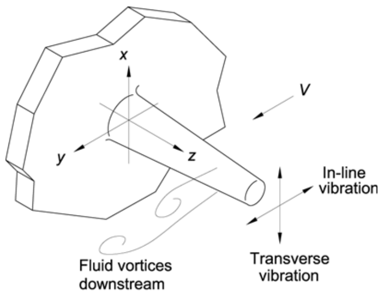
White Paper - Thermowell Calculations
00840-0200-2654, Rev AB
January 2012

Thermowells

Reynolds Number

In any fully immersed flow, a fundamental parameter is the Reynolds Number. The Reynolds Number is the ratio of the inertial forces to the viscous forces in the flow field. For the purposes of vortex shedding elements, the length input for the Reynolds Number is the width of the shedding element. In the case of thermowells, this is the tip diameter.

Thermowell Natural Frequency



Fluid induced forces and assignment of axes for calculation of thermowell stresses(1)

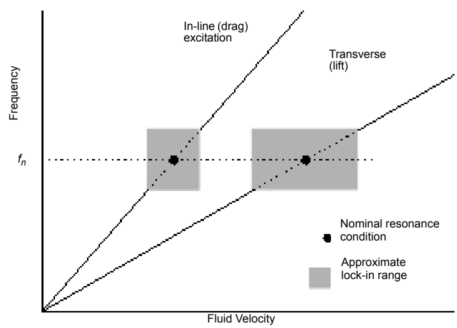
ASME PTC 19.3 TW-2010 models the thermowell as a simple cantilever beam and applies a series of correction factors to account for the differences from the ideal beam by including added fluid mass, added sensor mass, non-uniform profile beam, and mounting compliance. For stepped stem thermowells, most all the correlations and calculations are more complex due to the geometry and stress concentration points.

Because of this, ASME PTC 19.3 TW-2010 restricts the dimensional variation of stepped stem thermowells considered within the scope of the standard.

After all the correction factors are applied, the "in-situ", or installed natural frequency, f_n^c, is calculated and used for the rest of the frequency analysis.

Critical Velocities

Once the thermowell natural frequency has been established, the designer needs to set the margin of safety between the natural frequency and the Strouhal frequency.



In-line and transverse excitation schematic showing "lock-in" region.(1)

(1) *ASME Standard, Performance Test Codes 19.3TW-2010.*

There are actually two modes of thermowell excitation. The transverse (lift) force that causes the thermowell to vibrate perpendicular to the flow while the in-line (drag) force causes the thermowell to vibrate parallel to the flow. The in-line vibration is approximately twice the frequency of the transverse. The in-line "velocity critical" (where the Strouhal Frequency equals the natural frequency) is approximately half the velocity as the transverse. ASME PTC 19.3-1974 does not address the in-line vibration, only the steady state bending stress.(1)

While the change in the shedding frequency is proportional to the fluid velocity, the thermowell locks-in to the resonance frequency very easily. It can also take a considerable change in velocity to get the thermowell out of shedding vortices at its natural frequency. Since the damping of typical thermowells is very low, it is vital to stay out of resonance. At resonance the forces and displacements are greatly magnified.

$$f_s < 0.8\, f_n^c$$

The 20% guard band accounts for the significant variability due to:

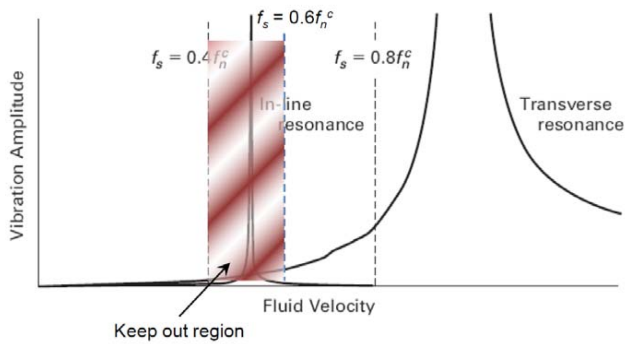
- the non-linearity of the thermowell elastic response
- loose thermowell manufacturing tolerances
- material property information established to only 3 significant digits
- minor, routine variations in flow rate, temperature, density, or viscosity in the process

Since the in-line vibration occurs at roughly half the velocity of the transverse (or twice the frequency), liquids have further limitations.

$$2f_s < 0.8\, f_n^c$$

Viewing this a bit differently gives a wider perspective on where thermowell operation is allowed.

$$f_s \text{ (steady state)} < 0.4\, f_n^c \quad \text{or} \quad 0.6\, f_n^c < f_s \text{ (steady state)} < 0.8\, f_n^c$$



Graph depicting the amplitude response of a thermowell to fluid-induced forces. (2)

(1) *ASME Standard, Performance Test Codes 19.3-1974 (Reaffirmed 1998).*
(2) *Adapted from ASME Standard, Performance Test Codes 19.3TW-2010.*

ASME PTC 19.3 TW-2010 also contains a provision for “super critical” operation where the thermowell is operated above the thermowell natural frequency. Emerson strongly discourages operating thermowells in this region.

Scruton Number

New to the theory is the use of the Scruton Number, which represents the intrinsic damping of the thermowell. ASME PTC 19.3 TW-2010 takes a very conservative perspective and sets the damping factor to 0.0005 unless it is otherwise determined.

A Scruton Number less than 2.5 means that there is no intrinsic damping and the thermowell must be evaluated at the in-line resonance frequency and stay away from the transverse resonance frequency. As the Scruton Number increases, there is an increased level of intrinsic damping that reduces the deflections and, therefore the stresses. An acceptable level of damping will allow the thermowell to operate at the in-line and maybe even the transverse resonance frequencies.

If the conditions are such that the thermowell will be operating above the natural frequency, higher order resonances must be considered, but ASME PTC 19.3 TW-2010 does not provide any guidance in this and Emerson strongly discourages operating thermowells in this region.

BENDING AND PRESSURE STRESS (as used in ASME PTC 19.3 TW-2010)

While it seems that there is a lot of attention being given to the vortex shedding theory and application, the stresses within the thermowell and forces applied are also critical to evaluating suitability for specific process applications. In contrast to the simple method in the 1974 version, ASME PTC 19.3 TW-2010 takes a much more detailed look at both the frequency and the stresses on the thermowell. This allows a wider variety of mounting styles, profiles, and bore sizes that reflect the offerings available in the industry today.

In total, there are 4 quantitative criteria in ASME PTC 19.3 TW-2010 for a thermowell to be found acceptable for a particular set of process conditions:

1. **Frequency Limit:** the resonant frequency of the thermowell must be sufficiently high so that destructive oscillations are not excited by the fluid flow.
2. **Dynamic Stress Limit:** the maximum primary dynamic stress must not exceed the allowable fatigue stress limit. If the design requires that the thermowell pass through the in-line resonance to get to the operating conditions, there is an additional fatigue check at resonance.
3. **Static Stress Limit:** the maximum steady-state stress on the thermowell must not exceed the allowable stress, as determined by the Von Mises criteria.
4. **Hydrostatic Pressure Limit:** the external pressure must not exceed the pressure ratings of the thermowell tip, shank, and flange (or threads).

In addition, the suitability of the thermowell material for the process environment must be considered. This means the designer must evaluate how corrosion and erosion affects the thermowell as well as how exposure to the process conditions affects material properties.

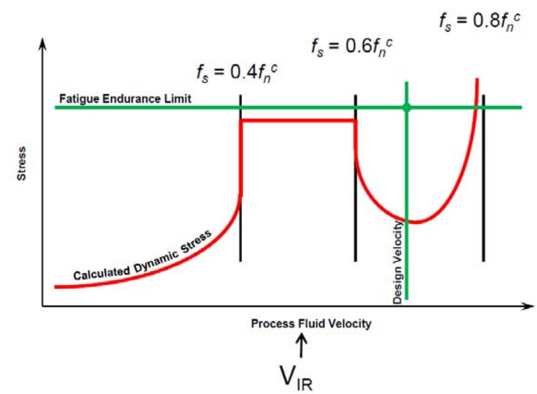
Frequency Limit

The vortex shedding theory section discusses the ASME PTC 19.3 TW-2010 method for Strouhal Frequency calculation. If the Strouhal Frequency is between the in-line critical frequency lock-in band and the transverse critical frequency lock-in band, and the Scruton Number evaluation indicates insufficient damping, the thermowell design must be modified unless all of the following conditions are met:

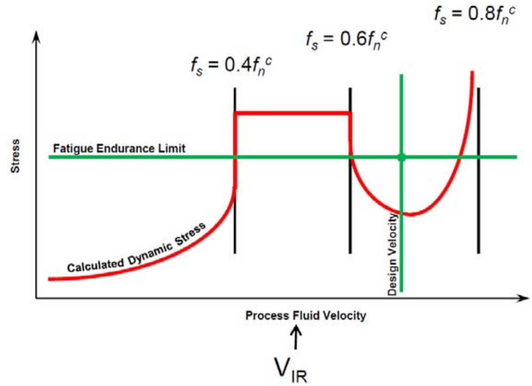
1. The process fluid is a gas
2. The thermowell passes through in-line resonance only during start-up, shut-down, or otherwise infrequently during operation
3. The peak stress at resonance is less than the fatigue limit of the material
4. The process fluid does not cause the material properties to change (esp. fatigue resistance)
5. The consequences of thermowell failure are an acceptable risk

Passing Through In-line Resonance

If the thermowell Peak Oscillatory Bending Stress is less than the Fatigue Endurance Limit at the in-line velocity critical, then the thermowell may pass through the in-line resonance lock-in region on the way to the steady state design velocity. Steady state velocities within the in-line resonance lock-in region are not allowed due to the high number of fatigue cycles imposed on the thermowell as well as the increased likelihood of sensor damage.

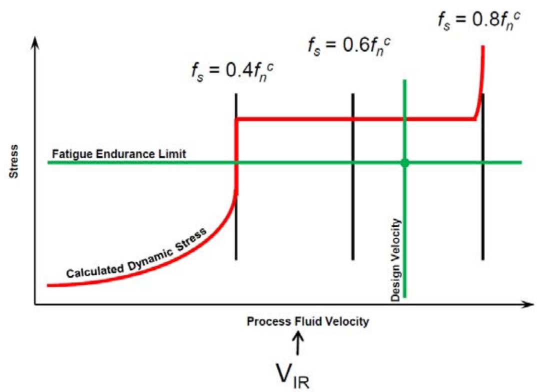


Example chart showing thermowell design that passes in-line resonance evaluation.



Example chart showing thermowell design that does not pass in-line resonance evaluation. This design may be acceptable per ASME PTC 19.3 TW-2010.

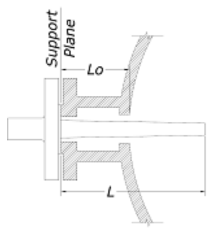
If the thermowell Peak Oscillatory Bending Stress is greater than the Fatigue Endurance Limit at the in-line velocity critical, there is more ambiguity about whether the thermowell can operate above the in-line velocity critical. Theoretically, if the thermowell is passing quickly through the in-line resonance lock-in region, it is allowed to operate between 0.6 f_n^c and 0.8 f_n^c. Fatigue cycle count is cumulative over the life of the thermowell, so it is critical to know how long the thermowell is in resonance. Since fatigue life is dependant on many factors, the longer the thermowell operates in resonance the less certain its lifespan.



Example chart showing how Emerson will interpret the in-line resonance evaluation. Emerson would find this design unacceptable.

Due to the fact that design details about ramp up speed are not known by the instrumentation providers, thermowells that do not pass the Peak Oscillatory Bending Stress evaluation and are operating above the in-line critical velocity will be reported as unacceptable by Emerson.

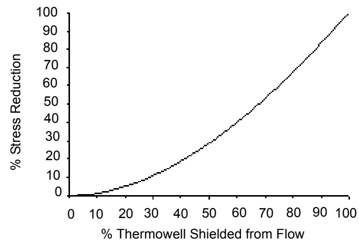
Thermowells Partially Shielded from the Flow



Tapered thermowell partially shielded from flow

Most thermowell installations are partially shielded from flow; the length of the thermowell exposed to the flow is not the full unsupported length and the equations for bending moment and bending stress need to be adjusted.

The effect of the shielding on a tapered thermowell is easily shown, but the effect of shielding on stepped stem thermowells is much more difficult to predict or model because the exposed surface is not a uniformly changing shape and there is a large discontinuity in the data. As a result, there are two sets of evaluations performed for stepped stem shielded thermowells based on the position of the step relative to the fluid flow. The stress calculations must also be performed twice to determine stresses at both the thermowell root and at the step.



Effect of shielding on a tapered thermowell

Once the installation and process conditions are understood as well as where the Strouhal Frequency sits in the frequency domain, the analysis of the actual stresses applied to the thermowell can be performed. As previously mentioned, if the thermowell is intended to operate above the in-line velocity critical, there are cyclic stresses at the in-line resonance to consider as it passes through that region on the way to the design velocity. Also the steady state and dynamic stresses at the design velocity must be evaluated.

Evaluation of In-line Cyclical Stress

The cyclic stresses, resulting from the in-line and transverse forces on the surface of the thermowell, are concentrated at the root. To account for the resonance conditions, the calculations must be performed at the in-line resonance velocity critical to see if the Peak Bending Stress at resonance is less than the Fatigue Endurance Limit of the material. Because this analysis is conducted at the in-line critical point, the magnification due to the in-line resonance overshadows the lift forces so the lift forces can be ignored to simplify the calculations. This evaluation need only be conducted if the Scruton Number evaluation indicates that the process conditions require it.

The in-line velocity critical is used to calculate the force per unit area applied to the thermowell. Since the process fluid velocity is given as an average rather than a velocity profile, the calculations also assume that the unit area is the entire exposed length of the thermowell. If some of the thermowell is partially shielded from the flow (as in the case of a standoff pipe), this must also be taken into account. For stepped stem thermowells, this analysis must be performed at both peak stress locations (root and base of stepped stem).

To ensure that the calculations are conservative, the intrinsic damping factor, is set to 0.0005. Stepped shank thermowells must be evaluated at two places to identify the highest stress of the two.

One of the major changes in the ASME PTC 19.3 TW-2010 is the use of a table to specify the Allowable Fatigues Stress Limits. The table groups materials together into a Material Class and cross references them to the installation method to determine the stress limit.

It is important to note that partial penetration welds are viewed as having less fatigue resistance than full penetration welds and are given lower values in this table. See Thermowell Construction Requirements below for more information.

Evaluation of Steady State Stress at Design Velocity

Thermowells must also be evaluated at the design velocity as well to ensure that they meet the demands of the process environment. The steady state stress is a combination of the external pressure from the process as well as the drag force. Again, these are calculated for the location of maximum stress, so if the thermowell is partially shielded, or if it is a stepped stem, the calculations should be performed with those installation considerations.

Once the Maximum Stress is calculated it can be used to determine if the Von Mises Criteria is met. The Von Mises Criteria is used to evaluate shear and pressure stress conditions in spheres and circular cylinders. It predicts the plastic yielding condition of materials.(1) Success in this evaluation means that the steady state stresses do not exceed the material fatigue strength and the thermowell can be used at the desired design velocity.

Evaluation of Dynamic Stress at Design Velocity

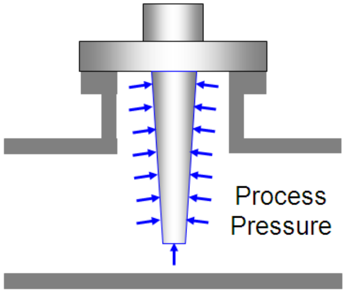
The dynamic stresses on the thermowell are attributed to the oscillating lift (transverse) and drag (in-line) forces. The magnification factor represents the exponential nature of the increase in forces as the Strouhal Frequency nears the thermowell natural frequency such as near the in-line velocity critical. If the Strouhal Frequency does not fall into the in-line or transverse natural frequency lock-in bands, then magnification factors are calculated and applied to the cyclical stress equations. The cyclic drag and lift forces need to be calculated at the design velocity in the same way as the in-line cyclical stress evaluation was performed. Unlike the in-line cyclical stress evaluation previously performed, the lift forces are not zeroed out.

If the design velocity is greater than the in-line velocity critical, the thermowell might have to be treated as if it will operate at in-line resonance stress levels indefinitely. See section above on Passing Through In-Line Resonance.

Obviously there are a number of evaluations performed on the thermowell design, but with information such as the in-line velocity critical, the steady state, and dynamic stress evaluations, the designer can have a detailed picture about where the thermowell is operating in the frequency domain as well as how close it is operating to its fatigue limit. This information will allow the designer to decide what safety factors to maintain in their process.

(1) Brock, John E., "Stress Analysis of Thermowells," Naval Postgraduate School, Monterey CA (1974).

Pressure Stress Evaluation



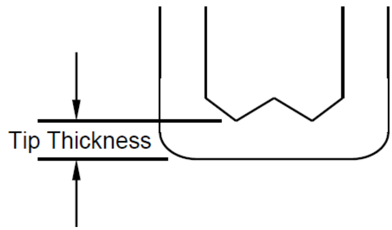
The final check necessary to see if the thermowell design is acceptable for the application is the pressure stress evaluation. This is often overlooked as it generally is not the cause of design unsuitability, but it is critical nonetheless. The pressure stress check must be performed on both the shank and the tip separately.

To calculate the pressure on the shank as a check for suitability there are two methods offered depending on the process pressure. For process pressures less than 103 MPa (15 ksi), ASME PTC 19.3 TW-2010 recommends using ASME Boiler Pressure Vessel Code (BPVC) Section VIII Paragraph UG-28, to calculate the allowable external pressure. The temperature restrictions listed in this section of the BPVC do not apply as most thermowells are designed under ASME B31.1 or ASME B31.3. Maximum allowable stress values should be sourced from either of those two standards instead. The reason the calculation from the BPVC is referenced in ASME PTC 19.3 TW-2010 is that the equation has a history of successful use and is relatively known in the industry.

In the event that the desired thermowell material is not in the BPVC or if a simpler method is desired, ASME PTC 19.3 TW-2010 provides an alternative simplified relationship. The drawback to using the simplified method is that the shank pressure determined by this method may be as much as 17% lower than the value calculated by UG-28 method for some materials at some temperatures. The benefit is a less complex calculation and an additional safety margin.

For high pressure (> 103 MPa (15 ksi)) applications, ASME PTC 19.3 TW-2010 points to ASME BPVC Section VIII Division 3 or ASME B31.3, Chapter IX for the calculation. Pressures this high (exceeding the pressure limits for 2500# flanges in ASME B16.5) will need to be carefully evaluated and not performed through an automated tool.

The tip thickness is the thinnest dimension from the outside tip to the furthest point of the drill. Since most thermowells are manufactured using gun drills, it is critical that the tip thickness used is the actual measure of the thinnest point. The peak dimension is used to calculate the sensor length since the peak will contact the sensor, not the “valley.” When the gun drill is sharp, the valley can be as much as 0.060” [1.5mm] deeper (thinner) and becomes thicker as the drill wears.



Thermowell tip thickness detail.

The maximum pressure that the thermowell can withstand is the lesser of the shank or tip pressure limit.

IMPORTANT NOTE:
Whether referring to ASME PTC 19.3 or ASME PTC 19.3 TW-2010, the pressure stress evaluation only refers to the stress that the thermowell stem (or shank) and tip can withstand, not what the thread or the flange can withstand. Process connection selection and pressure rating evaluation should be performed before the thermowell design is evaluated for vortex induced vibrations.

Materials Information

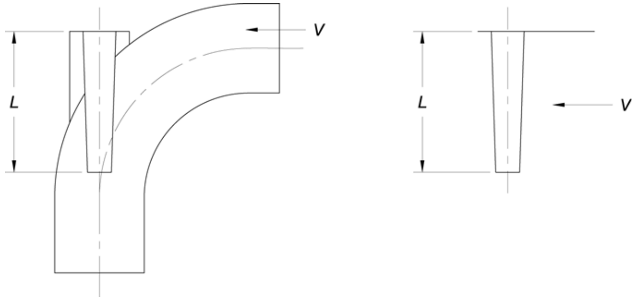
The best engineering practice for materials information is to use reliable and standardized information whenever possible. Emerson only uses materials information from open source standards such as ASME Boiler and Pressure Vessel Code and ASME B31.1/B31.3. This information is generally conservative and industry accepted. In theory, Emerson could use vendor information to populate our materials database. This practice is discouraged, however, because Emerson cannot ensure that a specific batch of material is used on a particular thermowell to match a particular report. This is not a practical or reliable method of optimizing thermowell performance.

INSTALLATION VARIATIONS

The manner in which thermowells are installed in a process can have a significant effect on the thermowell stress calculations and the vortex shedding. The variations discussed here are beyond the "standard" installations such as flanged, threaded, and welded thermowells, or partial shielding of the thermowell.

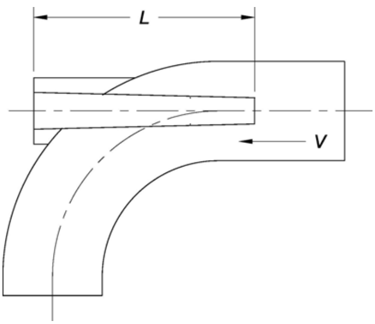
Elbow Installations

ASME PTC 19.3 TW-2010 gives no meaningful guidance on the installation of thermowells in an elbow. Modeling the flow in an elbow is extremely difficult due to the turbulence and complexity. ASME PTC 19.3 TW-2010 suggests that to be conservative, consider the entire unsupported, unshielded length to be exposed to the flow with the forces acting perpendicular (i.e. "normal") to the thermowell axis. To many, this is not an acceptable answer. Some comments in ASME PTC 19.3 TW-2010 and committee discussions yielded an alternative to this overly conservative view. If the tip is sufficiently upstream or downstream from the elbow such that the fluid flow is parallel to the thermowell axis at the tip, then the Strouhal Number is very small because the flow across the tip is negligible. ASME PTC 19.3 TW-2010 states that this is beyond the scope of the standard, while others in the industry maintain that this type of installation would be a simple solution for thermowell designs that are too close to the natural frequency.



Thermowell installed with tip facing downstream in an elbow.[1]

ASME PTC 19.3 TW-2010 suggests that the thermowell pointed in the upstream direction is the better installation because the amount and location of the flow stream applies a smaller moment arm and force to the thermowell and the flow over the tip is more laminar. If the tip is pointed downstream, the swirling of the fluid after passing around the thermowell could have some cross tip components, but this is extremely difficult to model. As with angled installations below, the moment arm calculation is complicated, therefore the changes in force, moment arm, and stress, are not easily predicted.



Thermowell installed with tip facing upstream in an elbow.[2]

Emerson is considering a more extensive investigation into these installation methods to provide some justification for the benefits of these solutions.

Angled Installations

Customers frequently install thermowells at an angle to the flow for accessibility, to reduce the forces acting on the thermowell, or to increase the exposure to the flow in smaller line sizes in order to obtain a more accurate temperature reading. The effect of the “yaw” angle on the tip velocity is not a matter of simple trigonometry. It also complicates the prediction of the stresses and forces acting on the thermowell.

(1) ASME Standard, Performance Test Codes 19.3TW-2010.
(2) ASME Standard, Performance Test Codes 19.3TW-2010.

9.2 – Proven Results

OIL & GAS ROSEMOUNT TEMPERATURE SENSORS

Improved Sensor Life in Gasification Reactor Applications Utilizing Sapphire Inner Tube

RESULTS

- Improve availability with fewer unplanned shutdowns
- Longer life thermocouples decrease Operating Expenses (OPEX)
- Enhanced safety features prevents release of emissions from the reactor
- Dual seal system improves process integrity

APPLICATION

- High temperature and high pressure processes
- Measuring temperature in various stages of the entrained flow gasification process for fluids and gases

APPLICATION CHARACTERISTIC

- Temperatures up to 1800 °C (3272 °F)
- Pressures up to 65 bar (943 PSIG)
- Contaminating gases such as Hydrogen and Carbon

CHALLENGE

The gasification process in the oil and gas, refining, and power industries impose difficult conditions to the measurement devices including temperatures up to1800 °C (3272 °F), pressures up to 65 bar (943 PSIG), and contamination that poisons thermocouples. These conditions lead to high costs from unplanned shutdowns, reduction in availability from thermocouple failure, and frequent replacement of thermocouples. Additionally, failure of conventional thermocouples may have safety implications by venting reactor contents to the surrounding atmosphere, which increases the risk of fire or injury to personnel.

SOLUTION

To meet these challenges, Emerson Process Management developed a high temperature thermocouple enclosed by a gas-tight sapphire protection tube. This procedure helps reduce thermocouple poisoning in the gasification reactor, and resulted in a thermocouple with triple the life of a conventional thermocouple.

By hermetically sealing the sapphire protection tube to the supporting bushing, Emerson Process Management created a process protected by United States Patent 6,059,453. In the event that the outer protective or inner sapphire tube breaks, the dual seal system prevents release of toxic emissions from the reactor. The process flanges and the connection housings are optionally available as forged versions to address leakage concerns of hydrogen containing gases.

Emerson Process Management continues to work closely with end users to improve process availability and safety in gasification applications.

OIL & GAS

The design and technical improvements provide exact, reliable temperature measurements and provides a life span ranging from 6,000 to 18,000 hours, dependant on the application process. Emerson Process Management continues to work closely with end users to improve sensor life in gasification reactor applications.

RESOURCES (OPTIONAL)

For more information, go to www.Rosemount.com or contact your local Emerson Process Management Representative.

Emerson Process Management
Rosemount Division
8200 Market Boulevard
Chanhassen, MN 55317 USA
T (U.S.) 1-800-999-9307
T (International) (952) 906-8888
F (952) 949-7001
www.rosemount.com

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Bognor Regis
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Enquiries@AP.EmersonProcess.com

ROSEMOUNT®

For more information:
www.rosemount.com

EMERSON™
Process Management

00830-0100-2654, Rev BA

CHEMICAL ROSEMOUNT 3144P

Chemical Company Reduces Uncertainty in Critical Ethylene Flow Measurement

RESULTS

- Temperature uncertainty reduced from ±0.7° F to 0.25° F
- Flow measurement uncertainty reduced by 65%
- Immediate payback on instrument investment

Gas flow rate uncertainty can be drastically improved when temperature error is reduced.

APPLICATION

Custody transfer of ethylene

CUSTOMER

Chemical company in Texas, USA

CHALLENGE

A chemical company in Texas needed to improve their flow measurement on a 6 inch (150 mm) ethylene line. Ethylene is a valuable feedstock, representing a sizeable investment. The annual throughput on the line was approximately 442,000,000 lb/yr (200,000,000 kg/yr) with a financial value of $250,000,000. It was critical that the flow measurement be as accurate as possible because even a small error could have a large financial impact.

Mass flow measurement was accomplished through pressure and temperature compensation of an orifice meter. A Rosemount 3144P temperature transmitter and a standard class B thin film RTD provided the temperature compensation for this meter. The sensor interchangeability error for this RTD is about ±0.7° F (0.4° C) at the flowing temperature of 68° F (20° C). Under normal flow conditions (100 inches H_2O (248 mbar) DP and 500 psig (34.5 bar)), the flow rate was 50,493 lb/hr (22,900 kg/hr). Because the indicated temperature could be up to ±0.7° F (0.4° C) in error, the flow measurement would be impacted by as much as ±2%. This would translate into $4,790,000 of measurement error per year.

SOLUTION

In order to improve the temperature measurement in this flow application, the company decided to take advantage of the transmitter-sensor matching capability of the Rosemount 3144P. The existing RTD was replaced with a Rosemount Series 68 RTD that included Callendar-Van Dusen constants specific to that sensor. By simply programming the four provided constants into the Rosemount 3144P, the temperature

CHEMICAL

measurement error was reduced by a factor of three - to an uncertainty of ±0.25° F (±0.15° C).

This simple change reduced the flow uncertainty due to temperature uncertainty from ±2% to ±0.675%. The financial implication of this measurement improvement totalled $3,100,000 over a one year period. Payback on the instrumentation investment was almost instantaneous.

By simply programming the four provided constants into the 3144P, the temperature measurement error was improved by a factor of three.

RESOURCES

Rosemount 3144P

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/Single-Point-Measurement/Pages/index.aspx

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EMERSON
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00830-0100-4021, Rev EA

METALS & MINING

SMART WIRELESS

Steel Mill Reduces Downtime, Improves Productivity Through Wireless Monitoring of Secondary Systems

RESULTS

- 5% productivity improvement, downtime reduced
- Eliminated coiling temperature rejects due to insufficient water flow
- Reduced downtime due to grease system failures
- Eliminated damage to roughing mill work rolls due to insufficient work roll coolant water
- Eliminated downtime due to back-up roll bearing failures

"I got the flow numbers I needed within 24 hours of installing the devices. Wireless is fantastic."

Gary Borham
Operations Manager
80" Hot Strip Finishing Mill

APPLICATION

- Run-out table cooling water flow
- Grease system pressure
- Work roll coolant pressure
- Back-up roll bearing lubrication temperature

CUSTOMER

Wheeling-Pittsburgh Steel Corporation, Mingo Junction, OH

CHALLENGE

Wheeling-Pittsburgh Steel Corporation is a progressive manufacturer and fabricator of selected metal products. When the Mingo Junction mill increased the product mix with a heavier and wider material, it required more run-out table cooling water to maintain the proper grain structure throughout the strip. Unfortunately, as the new product was being rolled the target coiling temperature could not be achieved. Manual valves used to scale the curtain flow to the proper setting for each product could not be confirmed with flow meters, since they were too expensive and difficult to install in this congested environment.

SOLUTION

When the run-out table was down, the customer installed four Rosemount 3051S Wireless Flowmeters, with Annubar® Primary Elements and one Smart Wireless Gateway. The measurements were easily integrated into the plant OSIsoft® PI System™ with a Modbus® interface through the gateway, where trending and reporting are done. "It only took two hours at the end of one day for a person to drill four holes and install the flow meters," said Gary Borham, Operations Manager, 80-inch Hot Strip Mill. "The next day, we installed the gateway, and had the whole system working. I got the flow numbers I needed within 24 hours of installing the devices. Wireless is fantastic." The flow information obtained from the wireless transmitters enabled Wheeling-Pittsburgh Steel to fine tune the sprays. Since then, coiling temperature rejects have been almost entirely eliminated.

METALS & MINING

SOLUTION (CONTINUED)

The ease of installation and cost of installing a wireless device compared to its wired counterpart has convinced Wheeling-Pittsburgh Steel to use wireless on many other monitoring applications. On the same run-out table a rash of roll failures prompted the customer to look at the grease system. The rolls which deliver the strip to the coilers can overheat, and any lack of lubrication can stop the roll which will cause strip surface defects. It was discovered that the grease system was malfunctioning and not adequately lubricating the roll bearings, creating downtime and impacting productivity. A Rosemount 3051S Wireless Pressure Transmitter was installed on the system and raises an alarm if the pressure drops or cannot be maintained, so preventative measures can be taken. This has eliminated downtime from rolls freezing up.

The mill was also experiencing work roll damage and subsequent downtime in the roughing mill due to coolant flow problems. The roll failure investigation uncovered a problem with a manual valve that was closing and dropping pressure and flow to rolls. Wireless pressure transmitters were installed on each roughing stand to insure a practice of maintaining constant flow and pressure of coolant to the work rolls. Since the adjustment and practices were put in place roll failures have disappeared.

The latest secondary system to benefit from wireless technology was the back-up roll bearings. Back-up roll bearing failures cause major downtime. The customer installed Rosemount 648 temperature transmitters in the drains to determine any increase in the inlet and outlet temperatures. If an increase is detected a small delay will occur to allow time to repair the problem. In the past bearing lock-ups would cause a lengthy delay in production while the back-up rolls were changed. Lengthy, unscheduled downtime has been replaced with short repair times, and costs due to equipment damage of the back-up rolls has been eliminated.

Borham concluded that wireless technology has allowed Wheeling-Pittsburgh Steel to gain process data almost effortlessly in areas where wiring would have been too costly. "We are building an infrastructure that opens up opportunities for more applications. The result is better information from difficult-to-reach areas of the mill, and this is helping our personnel prevent unscheduled downtime, meet customers' quality requirements, and optimize productivity."

"The result is better information from difficult-to-reach areas of the mill, and this is helping our personnel prevent unscheduled downtime, meet customers' quality requirements, and optimize productivity."

Gary Borham
Operations Manager
80" Hot Strip Finishing Mill

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00830-0100-4180, Rev AA

REFINING | ROSEMOUNT WIRELESS INSTRUMENTATION

Refinery Improves Environmental Compliance and Reduces Costs with Wireless Instruments

RESULTS

- Eliminated false Volatile Organic Compound (VOC) emission reports
- Reduced VOC emissions through timely operator intervention
- Minimized fines for VOC emissions through more accurate reporting
- Eliminated manual logs for compliance reporting

APPLICATION

Coking Unit in a Refinery

CUSTOMER

Refinery in North America

CHALLENGE

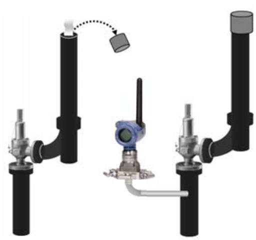
A refining customer in North America needed better monitoring of their pressure relief valves (PRVs) to track any release of VOCs more closely. Pressure relief valves allow a release only when line pressure builds up to a critical level, to prevent a more catastrophic failure due to overpressure. The Environmental Protection Agency (EPA) requires plants to report any VOC release, and assumes a worst-case scenario. That means the plant must assume the release happened immediately after the last logged entry, and that it lasted the full complement of time until the next logged entry. The plant is then fined accordingly. For this refining customer, that time was a 12 hour period.

The plant did not have resources to automatically monitor the pressure relief valves on the coking unit, so they put rubber "socks" on the stacks to indicate a VOC release. If a sock was off, a 12 hour emission at the maximum rate was assumed and reported. Unfortunately, VOC release wasn't the only culprit for a "sock-off" scenario. High winds sometimes blew the socks off, resulting in fines up to $350,000 for zero emissions. The plant did not have labor resources to manually monitor their PRVs more frequently than once a shift, and did not have $300,000 to engineer, design and install a traditional instrument network. They needed a more cost-effective solution to eliminate false emission reports, accurately report the length of time and rate for a true VOC release, and maintain a log to prove zero emissions.

The refinery found a solution that was 90 percent below the cost of a traditional wired network.

SOLUTION

The refinery found a solution that was 90 percent below the cost of a traditional wired network.This reliable and economical solution came from Emerson Process Management's Smart Wireless self-organizing network. The plant placed twenty-seven Rosemount 3051S wireless pressure transmitters on stacks in the coking unit to automatically monitor the high side of the pressure relief valves. This network provided coverage to an area spanning 1500 feet horizontally and 150 feet vertically.



A "sock off" situation (left) automatically assumed a 12 hour VOC emission at the maximum release rate. New wireless instruments from Emerson (right) provide trend data that can help operators prevent VOC emissions.

REFINING

The customer hired their standard contractor to engineer the instrument locations and install the network of devices. The contractor treated the devices as if they were wired, following their standard installation practices. There was no complicated site survey required to ensure wireless connectivity. They were placed on top of towers, at ground level, beneath the coking infrastructure, and between tanks. When the electrical sub-contractor installed the first 14 devices, they had perfect connectivity across the entire process unit. The self-organizing network allowed any device to talk to any other device on the network, so they had built-in communication redundancy at multiple levels. The network was strengthened when the remaining 13 devices were added according to the same standard installation practices.

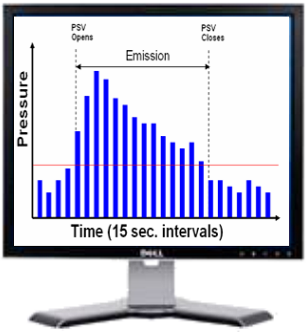
The instrument readings were seamlessly integrated into the existing OSIsoft® PI System™ through the 1420 Wireless Gateway for trending, analysis, calculation of VOC release rates, and automatic reporting of events. They provided high resolution data to prove environmental compliance; in fact, the rate of one point every fifteen seconds is four times the resolution required by the EPA for electronic equipment. The plant now has 2,880 data points per shift instead of one. They also have an actual pressure reading instead of a "sock on" reading. That pressure reading provides valuable trend history to generate alerts, and operators can take proactive steps to prevent an emission. Furthermore, instead of the "sock off" reading the customer now has the time of release within 15 seconds, as well as the actual rate of emission, so maximum pressure is no longer assumed. Finally, there are no more false positives from socks being blown off by high winds. The socks are still there, but only provide redundancy.

The result has been a significant drop in fines by eliminating false emission reports, prevention of VOC emissions through timely operator intervention, and true time and rate calculations for brief emissions that previously were assumed to be 12 hours at maximum pressure. A significant cost to the plant was also reduced with automated compliance reporting. Proving compliance is often more costly than compliance itself, and the plant was able to utilize their existing plant host to trend, analyze, report and prove zero emissions. The new technology has been openly embraced by IT, process operators, instrument technicians, contractors and engineers, and the customer plans to eventually install wireless devices on all 600 pressure relief valves in the refinery, both for stacks and drain pipes. Emerson Process Management's Smart Wireless technology enables any refining facility to cost-effectively meet new, stricter regulations.

RESOURCES

http://www.emersonprocess.com/rosemount/smartwireless/

The new technology has been openly embraced by IT, process operators, instrument technicians, contractors, and engineers.



The existing OSIsoft® PI System™ is used for trending and compliance reporting.

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00830-0100-4420, Rev AA

BULK CHEMICAL

SMART WIRELESS

Titanium Dioxide Pigment Manufacturer Increases Plant Availability with SmartPower™

RESULTS

- Increased plant availability
- Lowered maintenance and energy costs
- Reduced risk of low product quality

APPLICATION

Rotating calciner temperature measurement and control

CUSTOMER

Large chemical manufacturer in Southeast Asia

CHALLENGE

This titanium dioxide manufacturer had difficulty controlling a constant material temperature within their rotating calciner. The rotating calciner, which is about 40 m (131 ft.) long, has five temperature measurement points. The midpoint of these temperature measurements is used for burner control of the calciner.

The wireless temperature transmitters previously installed were purchased from a non-Emerson vendor. The devices on the calciner required frequent maintenance due to low battery life. Due to the rotation and vibration of the calciner, batteries often became misaligned. This caused intermittent measurement and resulted in soldering the battery connections. The batteries needed to be changed every one to two months because of low battery life.

The low battery life led to frequent shutdowns. These frequent shutdowns increased energy use and other operating costs. Maintenance costs were high, due to frequent battery replacement and damage to the kiln refractory liner. Inaccurate temperature measurements caused poor burner operation, which led to higher fuel consumption and higher emissions. Poor burner operation also risked low product quality.

The Rosemount 648 Wireless Temperature Transmitters allowed this pigment manufacturer to significantly improve availability of their rotating calciner and reduce unscheduled shutdowns.

The Rosemount 648 WirelessHART Temperature Transmitter

BULK CHEMICAL

SOLUTION

This customer's problem was solved with five new Rosemount 648 Wireless Temperature Transmitters. The Rosemount 648 utilizes Emerson's SmartPower™ technology, which significantly reduced the amount of time spent replacing the batteries. Intervals between battery replacement were increased by more than a factor of 10. The keyed connection feature eliminated alignment concerns and soldering requirements during battery replacement, Also, the self-organizing field network, provided exceptional data reliability and easy installation. The SmartPower technology also features an intrinsically safe power module that allowed field replacements without removing the transmitter from the process.

The Rosemount 648 Wireless Temperature Transmitters allowed this pigment manufacturer to significantly improve the availability of their plant and reduce unscheduled shutdowns for battery replacement. Also, maintenance costs decreased due to a reduction in trips to replace batteries and the kiln refactory liner. Energy costs decreased because the plant continued to operate at peak performance levels. In addition, having a reliable temperature control of the calciner resulted in reduced risk of low product quality, lowered fuel consumption, and decreased emissions.

RESOURCES

Emerson Smart Wireless
http://www.EmersonSmartWireless.com

Rosemount 648 Transmitter
http://www.emersonprocess.com/rosemount/document/pds/00813-0100-4648.pdf

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00830-0100-4648, Rev AA

LIFE SCIENCES

ROSEMOUNT 848T

Biotech Company Reduces SIP Cycle Time by 20%, Leading to Minimized Product Contamination

RESULTS

- SIP cycle time reduced by up to 20%
- Proven sterilization and minimized contamination
- 23% installation cost savings

Using the Rosemount 848T instead of the manual verification process reduced SIP cycle time by 10-20%.

APPLICATION

Steam/Sterilize in Place (SIP)

CUSTOMER

A Biotech Company

CHALLENGE

A Steam/Sterilize in Place (SIP) process is performed regularly in order to sterilize the process piping and vessels at the biotech company. The SIP process involves injecting steam and heating process piping to a kill temperature, often 121.1°C. Once the kill temperature is reached at all required points, the temperature is held for approximately 30 minutes to complete the SIP cycle.

Often no automated temperature instrumentation is used during the SIP process. Instead, a Tempilstik manual surface temperature indicator is used to manually verify that each test point on the vessel and process piping is at or above the kill temperature. Due to the frequency of SIP operations and the high density of temperature measurements (200 to 300 test points in an average site), using a manual surface temperature indicator to provide temperature verification is time-consuming. In addition, the inability to continuously monitor the temperature could result in process contamination.

SOLUTION

The Rosemount 848T Eight Input Temperature Transmitter is an ideal temperature measurement solution for this high-density temperature monitoring SIP application. The Rosemount 848T provides significant accuracy improvement over the manual verification process, and it enables continuous temperature monitoring at each SIP measurement point. This improves the customer's ability to consistently sterilize their process, thereby reducing the risk of contamination.

LIFE SCIENCES

The Rosemount 848T can provide a 20% or more installation cost savings.

Using the Rosemount 848T instead of the manual verification process reduced SIP cycle time by 10-20%. This is because all temperature points are simultaneously monitored instead of each point being measured one at a time until the ideal kill temperature is reached.

Additional time savings can be achieved by using continuous automated temperature monitoring to calculate the accumulated lethality factor (F_0) for each temperature measurement point. F_0 accounts for kill time at temperatures lower than the kill temperature. By using F_0 the user can reduce the amount of time that the system must be held at the kill temperature by accumulating lethality at temperatures below the kill temperature. On top of this, the customer now has the data available to prove that proper sterilizations were performed, since they are automatically monitoring the temperatures.

In the past, automated temperature monitoring methods such as sensors wired directly to I/O subsystems or single input transmitter architectures were not used in these applications because of the high material and installation costs associated with running hundreds of wires back to the control room.

In this application, the Rosemount 848T provided the customer with 23% installation cost savings by utilizing the FOUNDATION™ fieldbus protocol, mainly due to the reduced number of communication wires needed. The instrumentation used in this application consists of the Rosemount 848T and temperature sensors or RTDs. Temperature sensors are installed at each required temperature monitoring point, and each set of sensor lead wires is run back to a nearby Rosemount 848T. Rosemount 848T transmitters are mounted throughout the process area in small stainless steel junction boxes with each transmitter accepting eight sensor inputs. Up to 16 Rosemount 848T transmitters were strung together and run back to the control room, resulting in a single pair of wires communicating up to 128 temperature measurements.

RESOURCES

Rosemount 848T

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

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00830-0100-4697, Rev BA

REFINING ROSEMOUNT 644H

Refinery Eliminates Shutdowns Caused by Lightning

RESULTS

- Eliminated lightning-induced shutdowns over a three year period
- Improved signal reliability under heavy EMI conditions
- Increased production availability

The unit has not suffered any lightning induced shutdowns in over three years.

APPLICATION

Thermal reactor within a sulfur recovery unit where lightning-induced transients are prevalent

CUSTOMER

Refinery in North America

CHALLENGE

A North American refinery produces valuable light ends, hydrogen sulfide (H_2S), and ammonia. They had been experiencing multiple trips of their sulfur recovery unit due to high readings (spikes) from grounded thermocouples and temperature transmitters . These transmitters were used as safety interlocks in the thermal reactor. Upon investigation, the root cause pointed toward EMI/lightning induced transients transmitted either from the grounded thermocouples or field wiring to the field mounted temperature transmitters. The net result was nuisance interlock trips, shutdowns and loss of production.

SOLUTION

The refinery installed two Rosemount 644H Smart Head Mount Temperature Transmitters and the unit has not suffered any lightning induced shutdowns in over three years.

The Rosemount 644H incorporates a unique diagnostic algorithm designed to reduce or eliminate the effects of electrical transients, which can be induced via high voltage process equipment or lightning. The software solution that is available in every new 644H is called "Open Sensor Holdoff." The Open Sensor Holdoff option, at the normal setting, enables the Rosemount 644H to be more robust under heavy EMI conditions. This is accomplished by having the transmitter perform additional verification of the open sensor status prior to activating the transmitter alarm. If the additional verification shows that the open sensor

REFINING

condition is not valid, the transmitter will not go into alarm. This software diagnostic allows the 644 to maintain a good output through most electrical storms and transients without impacting operations and safety.

RESOURCES

Rosemount 644

http://www.emersonprocess.com/rosemount/products/temperature/m644.html

Emerson Process Management's Refining Industry Web Page

http://www.emersonprocess.com/solutions/refining/

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00830-0100-4728, Rev CA

BULK CHEMICAL SMART WIRELESS

Bulk Chemicals Manufacturer Improves Product Quality with Reduced Capital Cost by Using Smart Wireless

RESULTS

- Mitigated product quality risk
- Reduced operating costs
- Lowered installation and material costs

This wireless high density temperature transmitter was centrally located, allowing for a reliable and low cost solution for the temperature measurement.

APPLICATION
Cold box temperature monitoring

CUSTOMER
Bulk chemicals manufacturer in the United States

CHALLENGE
This bulk chemicals manufacturer was having problems maintaining temperature of the cold box. The cold box is used as a holding vessel to maintain product temperature before moving to the next process.

The temperature of the cold box was being measured with a simple thermocouple that was wired directly back to the DCS thermocouple input card. The direct measurement caused excessive temperature drift, which led to measurement unreliability.

The unreliable cold box temperature measurement presented a significant risk to product quality. Operations personnel did not trust the measurement and were constantly concerned about producing off-spec product and other downstream problems. Special field trips by operators to look at the local cold box temperature readings added to operating costs. The customer could not justify the capital costs needed in material and installation for more reliable temperature monitoring on the cold box.

SOLUTION
This customer's problem was solved with a Rosemount 848T Wireless Temperature Transmitter. This high density temperature transmitter was centrally located, allowing for a reliable and low cost solution for the temperature measurement. The 848T eliminated the measurement drift the customer previously experienced by eliminating the direct wiring practice. The Smart Wireless self-organizing network eliminated the costs associated with new wiring and additional conduit.

The best core technology, implementation practices, and field intelligence built into the Smart Wireless solution provided a positive business impact to this customer.

The Rosemount 848T Wireless

BULK CHEMICAL

The Rosemount 848T Wireless Temperature Transmitter allowed this bulk chemicals manufacturer to mitigate the risk of off spec product and downstream manufacturing problems. By providing reliable and continuous measurement of cold box temperatures, operating costs were reduced because special trips to the field were eliminated. These positive business benefits were realized at a reduced material and installation cost, compared to a wired solution.

RESOURCES

Emerson's Smart Wireless

http://www.emersonprocess.com/smartwireless/

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/index.html

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00830-0100-4848, Rev AA

INTERMEDIATE CHEMICAL | ROSEMOUNT AIS TEMPERATURE SENSORS

Intermediate Chemical Manufacturer Improves Quality with High Density, Non-Intrusive Temperature Measurement

RESULTS

- Improved quality
- Improved throughput
- Reduced maintenance cost
- Reduced energy cost

APPLICATION

Pipe heating-system temperature monitoring on intermediate chemical (MDI) transport lines

CUSTOMER

A Large Intermediate Chemical Manufacturer in Eastern Europe

CHALLENGE

This chemical manufacturer had challenges keeping an intermediate chemical in a foam state during transport. The company needed to better control temperature along the transport pipe.

Conventional temperature measurement using surface sensors with strap-on clamps didn't provide the needed accuracy and were slow to respond to temperature changes. Maintaining effective temperature control without over and undershoot was difficult. The sensor design made sensor replacement difficult and time consuming.

The temperature needed to be maintained very precisely to keep the product in a foam state. Temperature variations caused a dramatic loss of quality and throughput. The feedstock would disintegrate above the target temperature, while it would crystallize below the target temperature, plugging the pipes. A shutdown was then required to clean the pipes. In addition, the slow response to temperature changes wasted energy used to heat the transport pipe and contents. Finally, the time required to replace a failed sensor increased the risk of product loss or a process shutdown if a temperature sensor failed.

The Rosemount Pipe Clamp RTD Sensor and 848T Temperature Transmitter allowed the customer to better control chemical quality during transport.

Figure 1. Rosemount Pipe Clamp RTD Sensor

INTERMEDIATE CHEMICAL

SOLUTION

The manufacturer installed Rosemount Application and Industry Solution (AIS) sensors, which incorporated a non-intrusive pipe clamp design and Rosemount 848T Temperature Transmitters. The silver tip and spring loaded design of the sensors provided excellent thermal contact with the pipe and fast response to temperature changes. The use of RTD sensing elements provided a stable, reliable, and accurate temperature measurement. The easy-to-install sensor design combined with replaceable measurement inserts resulted in fast, easy installation and replacement of sensors when needed.

Utilizing the high performance pipe clamp RTD sensors and 848T Temperature Transmitters, more accurate temperature control was achieved. This improved the quality of the intermediate chemical and increased throughput. It also reduced maintenance costs by reducing the risk of feedstock crystallization in the pipe. In addition, better temperature control resulted in lower overall energy costs. Finally, the easy sensor replacement design reduced the risk of a shutdown if a sensor needed to be replaced.

Figure 2. Rosemount 848T Temperature Transmitter

RESOURCES

Emerson Process Management Chemical Industry

http://www.emersonprocess.com/solutions/chemical/

Rosemount Temperature

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

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BULK CHEMICAL

ROSEMOUNT AIS TEMPERATURE SENSORS

Leading Producer of Fertilizer and Ammonia Reduces Production Interruptions in Syngas Gasifier Process

RESULTS

- Increased gasifier availability
- Decreased risk of off spec product
- Lower operation and maintenance costs

The Rosemount Sapphire Temperature Sensors provided reliable performance in this high temperature, high pressure and corrosive environment.

APPLICATION

Temperature measurement in a Syngas Gasifier

CUSTOMER

Bulk chemical producer in Europe

CHALLENGE

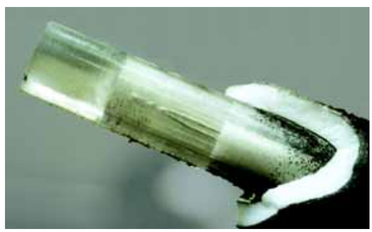
This leading producer of fertilizer, ammonia, and other bulk chemicals had a challenge controlling the temperature within its Syngas Gasifier. The gasifier converts super heavy waste oil into syngas.

Process conditions in the gasifier were very severe with temperatures greater than 1600 °C (2912 °F), a corrosive environment, and toxic gases. These conditions caused frequent and premature failure of the thermocouples that were previously used for gasifier temperature control. Hydrogen penetration into the thermocouple wire caused embrittlement and carbon penetration led to electrical shorts. Temperature cycling and thermal shocks also resulted in mechanical failure.

Frequent thermocouple failures resulted in several negative business impacts. Swapping thermocouples required the gasifier unit to be shutdown thereby causing reduced availability. Unreliable gasifier temperature measurements increased the risk of off spec product. Finally, routine thermocouple replacement led to high operations and maintenance costs.

SOLUTION

The problem was solved by installing a customized Rosemount Application and Industry Solution (AIS) Sapphire Temperature Sensor in the Syngas Gasifier. Sapphire sensor technology was better suited for the very high temperatures in this application. The sapphire sensor technology protected the thermocouple from the corrosive atmosphere with its protective tube and redundant seal system. The hermetic sealing of the sapphire protecting tube helped double the operational lifetime over the previously used thermocouples from 12 to 24 months and decreased the danger of environmental pollution.



Rosemount Sapphire technology protects the temperature sensor against corrosive atmospheres in high pressure and high temperature applications.

BULK CHEMICAL

The innovative Rosemount sapphire thermocouple sensor led to several positive business results for this bulk chemical producer. The AIS sensor increased gasifier availability and lowered maintenance costs by reducing the need to frequently replace unreliable thermocouples ill-suited for the severe application. The customer decreased the risk of manufacturing off spec product with improved gasifier temperature control.

The redundant seal system prevents toxic emissions from being released into the environment in high temperature and high pressure applications.

RESOURCES

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/index.html

Rosemount Temperature Sensors and Accessories

http://www.emersonprocess.com/rosemount/products/temperature/accessories.html

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EMERSON™ Process Management

00830-0200-2654, Rev AA

REFINING | ROSEMOUNT WIRELESS INSTRUMENTATION

Refinery Improves Availability of Coking Unit with Wireless Monitoring

RESULTS

- Improved availability of coking operation by reducing unplanned failure of expensive equipment
- Operator time freed up for higher value activities
- Up to 90 percent reduction in installed cost over traditional wireless network

APPLICATION

Calcining Unit for a Coking Operation

CUSTOMER

Refinery in North America

CHALLENGE

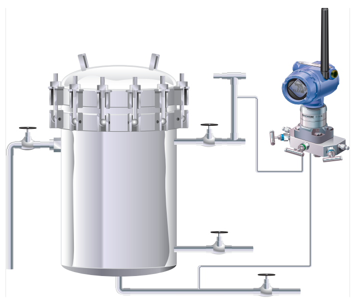
A refinery in North America wanted to automate non-production areas of their plant to free up labor resources for higher-value activities that improve plant productivity. Unfortunately, the high installed cost of traditional wired instrument networks was prohibitive, and they were forced to manually log most of their monitored points. Operators were visiting the calcining unit for the coker once a month and manually logging motor bearing temperatures, pump casing temperatures, differential pressure across water filters, and in-line pressures on chemical injection lines to detect plugging.

For the motor bearing and pump casing temperatures they had to manually take the readings for each of the three hearths with an infrared gun, then write them in a log and key the data into a data historian. This was in addition to any action that would be taken in case maintenance was needed. Because of limited resources, the refinery was seeking a cost-effective way to automate this area of the coker and free the operators from this time-consuming process. They also wanted to eliminate human error in logging each measurement and keying it into the historian. Finally, they wanted to improve resolution to the process and receive readings every hour instead of the current rate of once per month. They hoped to move from preventative maintenance techniques, which could result in unnecessary maintenance or unplanned failure of expensive equipment, to a proactive environment with predictable turnarounds. They needed an affordable, reliable measurement system that could handle the high humidity, high vibration, high EMF/RF environment as well as the extreme temperatures of -40°C to 85°C.

SOLUTION

The refinery installed a Smart Wireless self-organizing network from Emerson to monitor 14 points across a 1200 foot area of the coker and support units. Customers have estimated the cost of installing a traditional wired point is $8,000 to $15,000, including engineering and design for power and

Unplanned shutdowns are minimized because of more frequent and accurate bearing temperature monitoring.



Typical filter application

REFINING

communications, installation, and materials (excluding the cost of the instruments). In comparison, a wireless point on the self-organizing network only costs an average of $1,000 per point, representing a 90 percent reduction over the wired solution, which made the project feasible for the customer.

They installed the Rosemount 648 wireless temperature transmitter for motor bearing and pump casing temperatures and the Rosemount 3051S wireless pressure transmitter to monitor plugging of water filters and chemical injection lines. Emerson's 1420 Wireless Gateway was installed to connect the wireless instruments to the existing OSIsoft® PI System.™ Live process data as well as trend histories from the calciner are now available to operators, instrument technicians, engineers and management through their existing PI System.

Very little training was required, since Rosemount wireless devices can be installed exactly the same way as wired devices. The customer had their own people install and start up the equipment; they did not need Emerson engineers. In fact, one instrument engineer acknowledged that the instruments look exactly like their wired counterparts.

Now the plant monitors bearing temperatures more frequently and accurately, and is able to detect problems in motor and pump casings before they lead to unplanned failure. On the first day of installation, the plant engineers noticed the bearings on one hearth were running 30°C hotter than optimal. They installed a cooling system to prolong the life of that equipment and prevent an unplanned shutdown. The bearing temperatures for all three hearths are used to modify the capacity at which the calciner is operating. If the motor or pump casing temperatures go above a critical point, plant engineers reduce the capacity of the calciner so the motors can safely run until the next scheduled turnaround without damaging their equipment. Other equipment like filters has been optimized by higher accuracy and higher resolution to the process. Back flushing is no longer based on a set schedule, but is performed as needed based on the differential pressure trend history in the historian. This has prevented filter plugging and subsequent downtime as well as reducing unnecessary maintenance activities.

The operators still make rounds, but without an infrared gun and a manual log. They use a wireless PDA to interrogate their wireless instruments and connect to the data historian to check trend histories. Their focus is now on solving problems instead of manually reading, logging and entering data. With higher resolution to the process and more accurate measurements, the plant has improved the availability of the coking operation, streamlined maintenance activities, moved the plant to predictable turnarounds, and minimized unplanned failures of expensive pumps and motors.

Very little training was required because Rosemount wireless devices can be installed exactly the same way as their wired counterparts.

RESOURCES

http://www.emersonprocess.com/rosemount/smartwireless/

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00830-0200-4420, Rev AA

COAL POWER

ROSEMOUNT 648 WIRELESS TEMPERATURE

WE Energies Automates Dewatering Bin Sludge Level Measurement and Monitors the Result Without Wires

RESULTS

- Improved personnel safety
- Reduced operations and maintenance cost
- Reduced project implementation cost

APPLICATION

Ash level measurement in the bottom of an Ash Dewatering Bin

CHARACTERISTICS

Very cold temperatures during the winter months; murky water

CUSTOMER

WE Energies, Upper Pensinsula of Michigan, USA

CHALLENGE

Ash from the bottom of a boiler must be removed. This ash is mixed with water to form slurry which is carried to dewatering bins where the ash is concentrated for disposal. When the ash in the bottom of the bin reaches a predetermined level it is pumped out. WE Energies' power plant needed to reliably measure the level of ash in the bottom of a dewatering bin.

Customer had been using a “yo-yo” system to monitor the sludge. A weight on a string is dropped into the bin until it hits the sludge. As the weight is reeled back, a servo motor determines the length of string and sludge level is calculated. Maintenance personnel needed to manually read and record the level measurement. During the winter months, the wet string caused the device to freeze up even though it has a heat blanket. The result is a lost level measurement, and the need for maintenance to repair the frozen device.

WE Energies experienced several negative business consequences as a result of the unreliable ash level measurement. In winter, snow, ice, and cold presented safety risk to maintenance personnel needing to climb to the top of the dewatering bin. The need to maintain the frozen “yo-yo” measurement device increased maintenance costs. Finally, due to the loss of the ash level measurement, ash was sometimes pumped from the dewatering bin before reaching the desired level. This increased operations cost.

Mobrey MSL600 Sludge Blanket Level Monitor and Rosemount 648 Wireless Temperature Transmitter

SOLUTION

WE Energies installed a Mobrey MSL600 Sludge Blanket Level Monitor to measure the ash level. The monitor uses sonar technology to make a continuous measurement. The sensor is mounted below the water level and has no moving parts that can freeze. The output from the MSL600 was sent to a Rosemount 648 Wireless Temperature Transmitter. The 648 wirelessly sent the level reading to the control room. The system has operated successfully through the harshest winter months without requiring any maintenance and had no downtime. In addition, plant personnel no longer need to climb to the top of the bin to read and record the sludge level.

WE Energies experienced several positive business results by automating the sludge level measurement with the Mobrey MSL600 and Rosemount 648. First, personnel safety has been improved by eliminating the need to climb to the top of the bin to manually take the level measurement. Second, unscheduled maintenance on the bin level measurement has been eliminated, reducing maintenance cost. Third, ash pumping cost was reduced due to elimination of unnecessary ash pumping. Finally, by wirelessly communicating the level measurement to the control room, the cost of installing wires was eliminated reducing implementation cost. The installation has been so successful that additional Ash Dewatering Bins on site are being upgraded with this solution.

RESOURCES

Emerson Process Management Power Industry

http://www.emersonprocess.com/solutions/power/index.asp

Mobrey MSL600 Sludge Blanket Level Monitor

http://www2.emersonprocess.com/en-US/brands/mobrey/Level-Products/Ultrasonic/MSL600/Pages/index.aspx

Mobrey MSL600 Sludge Blanket Level Monitor

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/Single-Point-Measurement/648-Wireless/Pages/index.aspx

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00830-0200-4648, Rev AA

POWER | ROSEMOUNT AIS TEMPERATURE SENSORS

OEM for Power Generation Equipment Reduces Maintenance Costs with Flexible Sensor Tip Design

RESULTS

- Decreased maintenance costs
- Reduced risk of plant downtime
- Decreased risk of damage to equipment

APPLICATION

Thrust and journal bearing metal temperatures

CUSTOMER

Leading turbine and compressor OEM in India

CHALLENGE

This OEM had a problem with measuring thrust and journal bearing temperatures for newly manufactured turbines and compressors. These temperature measurements must be closely monitored so that the bearings do not overheat and break.

The temperature sensors had to be inserted into the bearing housings with tight space restrictions. The rigid design of the sensor had an insufficient bending radius that led to sensor tip failure during installation, and vibration of equipment during load testing.

The rigid temperature sensor design resulted in increased maintenance costs due to frequent temperature sensor replacement. Unreliable bearing temperature measurements also risked damage to equipment, resulting in downtime for their customers.

SOLUTION

The rigid temperature sensors were replaced with customized Rosemount Application and Industry Solution (AIS) Sensors, which incorporated more flexible probes and sensor tips. The 5mm bending radius at the sensor tip allowed the OEM to monitor the temperatures within the tighter space confines around compressors and turbines.

The technology and implementation of the Rosemount AIS Sensors eliminated the problems experienced with the previous temperature sensors. This reduced maintenance costs, risk of damage to equipment, and downtime for this OEM's customers.

The Rosemount AIS Sensor allowed the OEM to monitor the temperatures within the tighter space confines around compressors and turbines.

Flexible Thermocouple Sensors 5mm, K Type Triplex (for Steam Turbines)

Flexible Pt100 Thin Film RTD Sensors 3.2mm Duplex (for Compressors)

POWER

RESOURCES

Rosemount Application and Industry Solution (AIS) Sensors

http://www.emersonprocess.com/rosemount/products/temperature/accessories.html

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PULP & PAPER | SMART WIRELESS

Lime Kiln Throughput Improves with Smart Wireless Solution

RESULTS

- 5% throughput improvement in lime kiln
- Minute-by-minute mid-zone temperature trending
- Self-powered transmitters were sending temperature updates within 24 hours of delivery
- Communication of devices on opposite sides of a rotating kiln to one Gateway

"... four days after the order was placed, we could see minute-by-minute mid-zone temperatures trending on the control system."

Pulp Mill E&I Leader

APPLICATION

Lime Kiln Mid-Zone Temperature

APPLICATION CHARACTERISTIC

Rotating kiln, high temperature, radiant heat, dusty ambient environment

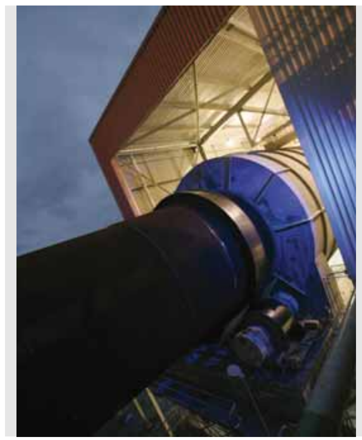
CUSTOMER

Pulp and Paper Mill in North America

CHALLENGE

A Pulp and Paper Mill in North America struggled to properly control calcining in the lime kiln. In fact, the kiln was operating so poorly that it had become a choke point. The mill bought a new burner system and adjusted the flame profile to improve heat transfer at the mid-zone, where calcining of the lime mud takes place. The burner system is fired at the hot end (2000 °F [1093 °C]) of this long, cylindrical, rotating kiln and a draft is induced at the feed end (400 - 500 °F [204 – 260°C]). The flame is adjusted through the draft to provide the optimum shape and achieve the right mid-zone temperature. For this mill, however, the mid-zone temperatures could not be measured reliably and were inferred through the firing and feed end temperatures.

Unfortunately, the new burner system did not solve the problem. The mill suspected a new chain system was needed on the inside of the kiln to break up the lime mud and promote heat transfer. The Pulp Mill Leader did not want to invest the money, however, until the mid-zone temperatures for the center of the kiln (the air temperature) and the inside wall (where lime mud tumbled around chains) could be measured and actual heat transfer could be confirmed. The temperature measurement that had accompanied the purchase of the kiln, which relied on a brush system, had never worked and had not been maintained. A wired solution could not handle the rotating equipment, so the customer approached their instrument partner - Emerson Process Management - for a solution.



Lime Kiln Application

PULP & PAPER

SOLUTION

Emerson Process Management's new Smart Wireless solution was proposed, and the customer asked for shipment as soon as possible. Two Rosemount 648 Wireless Temperature Transmitters with thermocouples and a 1420 Gateway arrived at the plant three days later. The sensors were installed on opposite sides of the kiln's mid-zone, 180° apart, without thermowells to provide the fastest possible response time. One was positioned toward the center of the kiln to pick up the air temperature, and the other was positioned at the outer extremity to pick up radiant heat from the brick, indicating lime mud temperature. The self-powered transmitters were mounted on a pipe that extends away from the kiln and were sending temperature updates to the control room through the 1420 Gateway within 24 hours of delivery. "We had a Modbus® address available, so it was easy to add the Gateway as a slave to the control system," said E&I Leader for the Pulp Mill and Lime Kiln. "In fact, four days after the order was placed, we could see minute-by-minute mid-zone temperatures trending on the control system."

Immediately the mill recognized the inferred temperatures were off by 350 °F (177 °C), and confirmed that a new chain system was required to break up the lime mud. "Since the wireless system has been installed, we can tell if there's build-up of lime in the mid-zone area," said the Pulp Mill Team Leader, "You can see fluctuation in the temperature, which is an indication of build-up. Overall, we have improved operation of the lime kiln, and increased throughput by 5%." The Pulp Mill Team Leader concluded by saying, "I think it's a pretty good achievement to have two different devices communicating with one Gateway, when they are on opposite sides of a rotating kiln.

"Since the wireless system has been installed, we can tell if there's a build-up of lime in the mid-zone area. . . .Overall, we have improved operation of the lime kiln, and increased throughput by 5%."

Pulp Mill Team Leader

RESOURCES

http://www.emersonprocess.com/smartwireless

Standard Terms and Conditions of Sale can be found at www.rosemount.com\terms_of_sale

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00830-0300-4180, Rev AA

FOOD & BEVERAGE EMERSON 648 WIRELESS

Food Manufacturer's Regular Maintenance Cost and Production Downtime Reduced by Wireless Solution

RESULTS

- Increased roaster availability
- Faster roaster startup
- Higher production throughput
- Improved quality
- 10,000 USD saved in maintenance costs

The Rosemount 648 Wireless Temperature Transmitter enabled an estimated savings of 10,000 USD by eliminating the need to maintain a slip ring assembly prone to oxidation.

APPLICATION

Temperature measurement of product inside a rotating roaster

APPLICATION CHARACTERISTICS

Roaster rotating at 30 to 35 rpm

CUSTOMER

Food Manufacturing Company in Asia

CHALLENGE

Accurate and reliable temperature measurement is important in maintaining quality of roasted products. The Instrumentation Engineer of this food manufacturing plant wanted to eliminate regular maintenance of the slip ring assembly used to measure product temperature inside a rotating roaster. Reducing downtime due to maintenance would mean increased roaster availability and thus increased production throughput.

Two thermocouples wired into a slip ring assembly were used to measure the surface temperature of the rotating roaster. The slip ring converts the temperature reading into resistance and sends it to a Distributed Control System or DCS. Due to high temperature and high humidity of the roasting process, the slip ring contacts began to oxidize sending out erratic readings.

Without accurate temperature measurement, the product would get over-roasted and affect quality. In addition, a fire could potentially occur due to unchecked high process temperature once the slip ring assembly oxidizes. To mitigate this risk, the roaster needed to be turned off so a replacement assembly could be installed. Since it takes about four production days to finish surveying the roaster and mold a new slip ring assembly, frequent oxidation of the slip rings not only increased maintenance cost, but lost four days of production as well.

FOOD & BEVERAGE

SOLUTION

The Instrumentation Engineer replaced the slip ring assembly with a Rosemount 648 Wireless Temperature Transmitter. This eliminated the need to use a slip ring assembly which was prone to oxidation. The existing thermocouples were connected to the wireless transmitter, which transmits surface temperature measurements to a Smart Wireless Gateway. The wireless network is then integrated into a DCS with OPC to allow data tracking to maintain product quality. The Rosemount 648's Transmitter-Sensor Matching feature eliminates sensor interchangeability error, improving accuracy of measurement for better quality control.

By replacing the slip ring assembly with a Rosemount 648 wireless solution, the plant was able to save an estimated 10,000 USD on maintenance cost. They were also able to improve production throughput as the roaster downtime due to maintenance of the slip ring assembly was eliminated. And with a robust and accurate temperature measurement integrated into a DCS, product quality can be easily monitored and maintained.

Rotating roaster drum with a Rosemount 648 Wireless Temperature Transmitter

RESOURCES

Emerson Food and Beverage Industry

http://www.emersonprocess.com/foodandbeverage/

Emerson 648 Wireless Temperature Transmitter

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/Single-Point-Measurement/648-Wireless/Pages/index.aspx

Rosemount 648 Wireless Temperature Transmitter

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EMERSON
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00830-0300-4648, Rev AB

METALS & MINING ROSEMOUNT SMART WIRELESS

Steel Mill Increases Throughput and Improved Safety with Wireless Technology

RESULTS

- Increased Throughput
- Improved Safety
- Reduced Operations and Maintenance Costs
- Reduced Energy Costs

With the Smart Wireless solution, the furnace is producing up to one additional batch per day. Each batch is valued at $200,000.

APPLICATION

Electric arc furnace (EAF) temperature control, 28 points, 24 for control, 4 for monitoring

CHARACTERISTICS

Extreme temperatures up to 3000 °F, very high EMF, ambient temperatures of ~140 °F.

CUSTOMER

Northstar Bluescope Steel, Ohio, Mini Mill

CHALLENGE

The water temperature of furnace-cooling panels must be controlled in order to prevent runaway temperatures and panel failures. Water-cooled burners are monitored to control energy to the burner to help prevent burner failures. Alarms are processed through PLCs and controlled through SmartArc transformer regulation and burner control.

There were 28 different measurement points, each with ten different wiring junction connections between the sensor and the PLC. Vibration, moisture, and heat could cause connection failures, leading to lost measurements and changes in connection resistance, leading to large measurement errors. Large chunks of slag could be ejected from the furnace-damaging cable or conduit up to 80 feet from the furnace. In addition, physical damage could occur when the furnace top is opened to charge the furnace. Each week between 9 and 12 measurements would fail.

Figure 1. Cooling Panel

METALS & MINING

Continued operation of a furnace with failed measurements presents a safety risk, so if a measurement point fails, the furnace must be shut down. If the furnace overheats, a cooling panel can blow out. The panel cost $20,000 to repair and lead to lost production. Average RTD cost is $250. An additional $750 per week is spent in maintenance labor costs. High temperature cable costs about $4 per foot. Excess temperatures caused by missing or inaccurate measurements can damage the furnace, and present a significant safety risk. Each furnace was typically shut down one day per week at which time, sensors and wiring were repaired. Loss of production from the shutdown costs about $500 per minute.

Figure 2. Installed Rosemount 848T Wireless High Density Temperature Transmitter

SOLUTION

Six 848T and four 648 wireless temperature transmitters were used to monitor 28 temperature points, 24 on the furnace body and four on the lid. The 28 points are brought into the PLC using a Smart Wireless Gateway. The wireless solution eliminated almost 100% of the cable and conduit thus eliminating cable and conduit damage. It also eliminated temperature measurement errors caused by changing contact resistance in the RTD wiring.

This solution has been up and running for four months without a single failure. Maintenance costs have been reduced by $200,000 per year. Safety has been improved as workers now know that the cooling panels of the furnace are at a safe temperature for operation and maintenance, and less maintenance is required around the hot furnace shell. More accurate temperature monitoring has reduced the risk of damage to capital equipment, and better temperature control has resulted in shorter batch times. Each additional batch is valued at about $200,000. Up to one additional batch a day is being produced for a potential value in excess of $50,000,000 per year.

RESOURCES

Rosemount Smart Wireless

http://www2.emersonprocess.com/en-US/brands/rosemount/Wireless/Pages/index.aspx

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00830-0300-4848, Rev AA

OFFSHORE

ROSEMOUNT AIS TEMPERATURE SENSORS

Offshore Oil Producer Minimized Risk of Reduced Production and Well Availability with Non-intrusive Temperature Measurement

RESULTS

- Minimized risk of reduced production and well availability
- Decreased operations and maintenance costs
- Reduced safety risks

APPLICATION

Flowline Temperature Monitoring

CUSTOMER

Oil producer in Thailand

CHALLENGE

This offshore producer experienced difficulties with paraffin buildup inside their flowlines. Paraffin buildup restricted the internal diameter of the flowlines, resulting in reduced oil flow.

A primary cause of this customer's challenge was that there was no surface temperature measurement. Without this information, the oil producer was unable to detect when the conditions for paraffin buildup were present. Also, the customer required that no pipe penetrations or welded connections be part of this installation, which risk failing under high vibration conditions.

The absence of a flowline temperature measurement increased the risk of reduced production and well availability due to paraffin buildup. The customer experienced increased operations and maintenance costs when removing the paraffin obstructions with manual intervention and chemical injection. Lastly, offshore personnel had to enter hazardous areas, exposing them to increased safety risks during paraffin removal.

SOLUTION

The offshore oil producer reduced the possibility of paraffin buildup by installing customized Rosemount Application and Industry Solution (AIS) Sensors, which incorporated a non-intrusive pipe clamp sensor design. The non-intrusive design eliminates insertion into the process, and is quickly installed on the external piping.

The Rosemount 644 Temperature Transmitter, used in conjunction with the Pipe Clamp RTD Sensor design, enabled the customer to quickly install temperature measurements in areas where paraffin buildup was common. The temperature measurements helped the customer to be proactive, and reduce paraffin buildup within the production flowlines.

The Rosemount 644 Temperature Transmitter with Pipe Clamp RTD Sensor design allowed this customer to detect paraffin buildup, saving operations and maintenance costs.

The Rosemount 644 Temperature Transmitter used in conjunction with the Pipe Clamp RTD Sensor design

OFFSHORE

The technology and ease of implementation with the Rosemount 644 Temperature Transmitter and Pipe Clamp RTD Sensor design enabled this customer to minimize the risk of reduced production and well availability due to paraffin obstructions. Decreased operations and maintenance costs were a result of proactive temperature monitoring and the early detection of conditions that result in paraffin buildup. Finally, the producer lowered their safety risks by reducing personnel exposure to hazardous areas.

RESOURCES

Rosemount 644 Head and Rail Mount Temperature Transmitters
http://www.emersonprocess.com/rosemount/products/temperature/m644.html

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00830-0400-2654, Rev AA

OIL AND GAS **ROSEMOUNT 848T**

Temperature Instruments Secure Critical Start-Up Deadline on Lube Oil Project

RESULTS

- Reduced commissioning time
- Reduced installation costs
- Reduced troubleshooting time

The Rosemount 848T and 3420 allowed the customer to complete startup and commissioning in one day.

APPLICATION

Temperature control and monitoring

CUSTOMER

Lubricant Manufacturer in Malaysia

CHALLENGE

A "Hot Oil Improvement Project" at a lube oil blending facility in Malaysia called for the addition of 23 temperature measurement points for control and monitoring of the process. These measurements were required to ensure the process was kept at a constant temperature prior to a chemical addition stage of the process. This process is critical to the quality of the final lube oil product.

This was a fast track project that required quick deliveries to coincide with the availability of electrical contractors. The engineers had two main concerns: the installation and start-up had to be quick and trouble free, and because they were on a tight budget, installation costs had to be contained.

SOLUTION

Emerson engineers identified Fieldbus wiring as the key to reduce the installation costs. They also recognized the value of Fieldbus instrumentation with diagnostic capabilities to speed commissioning. They recommended three Rosemount 848T Temperature Transmitters and a 3420 Fieldbus Interface Module.

Installation

Each Rosemount 848T is mounted in a junction box near the sensors to minimize sensor wiring and improve performance. Installation costs can be reduced by as much as 70% when compared to traditional sensor wire direct applications because each 848T accepts eight temperature inputs and have one cable for the fieldbus output. The fieldbus output runs to a Rosemount 3420 Fieldbus Interface Module that converts the information

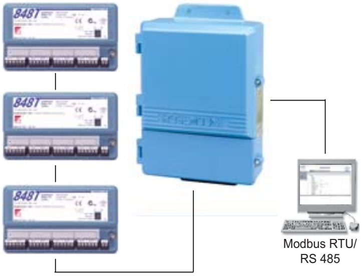
Rosemount 848T 8 Input Temperature transmitter with FOUNDATION™ Fieldbus

OIL & GAS

to a standard Modbus RTU signal. This signal is then run to the DCS. The Rosemount 848T is a highly flexible temperature transmitter due to its ambient temperature limits, RFI immunity compliance, intrinsically safe approvals, and ability to mount in industrial environments.

Configuration, Commissioning, and Diagnostics

Configuration of the field devices is done via the Ethernet connection of the Rosemount 3420 using any PC with a web browser. Because the 3420 automatically detects connected Fieldbus devices, the need for loop checks is eliminated thus reducing commissioning time. The 848T's ability to detect sensor open or short diagnostic speeds troubleshooting in both startup and maintenance situations. The Rosemount 848T and 3420 temperature measurement solution allowed this customer to complete start-up and commissioning in one day!



Rosemount 848T temperature transmitters networked to a Rosemount 3420 Fieldbus Interface Module for minimum cabling and installation costs.

RESOURCES

Rosemount 848T

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Rosemount 3420

http://www.emersonprocess.com/rosemount/products/accessories/m3420.html

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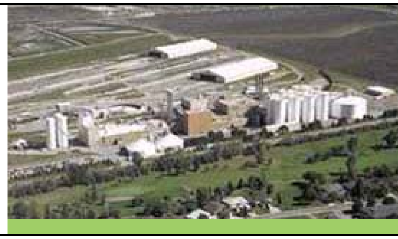
00830-0400-4697, Rev BA

FOOD & BEVERAGE | EMERSON SMART WIRELESS

Temperature Technologies Provide New Insights to Improve Safety, Productivity at American Crystal Sugar

RESULTS

- Improved plant safety
- Greater visibility in hazardous areas
- 2.5% reduction in operations time for higher operator productivity
- Improved pond management
- Ready for new upcoming EPA reporting requirements



APPLICATION

Monitor bearing temperature and motor current in Weibull Bins (sugar silos) and conveyor system to prevent ignition point; remote monitoring of settling ponds.

CUSTOMER

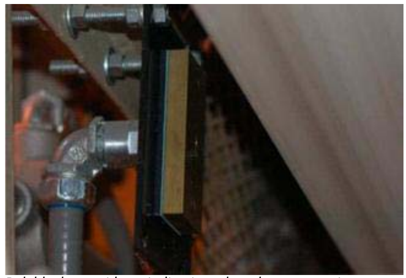
American Crystal Sugar (ACS), East Grand Forks, MN

CHALLENGE

Sugar dust in safety equipment caused a small explosion at a sugar refinery near Savannah, GA. Just eleven days earlier, a similar but bigger blast killed nine workers at a Port Wentworth, GA plant according to a federal investigator. Alerted to the potential danger of sugar dust, American Crystal Sugar (ACS) proactively searched for ways to prevent a similar accident in its plants. The company looked to measure abnormal situations where field equipment could become potential ignition points in hazardous areas, including hazardous dust in the Class II Div 1 & 2 Group G.

"We first identified equipment and devices that were potential ignition points," said Gary Phelps, Electronic Control Technician for ACS. "We were looking for devices that were not ignition sources under normal conditions, but had the potential to become ignition sources under abnormal situations." Bearings and motors in the sugar silos where sugar dust was in the greatest concentration were the first to be identified, as were misaligned conveyors that delivered the sugar from the silos to the sugar handling area.

"We identified the bearings on the sugar conveyor system as well as the misaligned conveyors, as both could heat up and potentially introduce an ignition point," said Jay Sorum, also an Electronic Control Technician for ACS. "Even sealed bearings can fail, and create an ignition point.



Rub blocks provide an indication when the conveyor is even slightly out of alignment. A conveyor out of alignment can be a potential ignition source.

Sugar silos at ACS in EGF have a rotating bridge that made wired instrumentation impossible to implement.

FOOD & BEVERAGE

Conveyor belts, too, have the potential if they become even slightly misaligned."

The challenge was installing an instrument network that had high reliability and performance with a low installed cost. In the sugar silos, an additional challenge was introduced. "The sugar silos are about 75 feet high and 100 feet across," said Phelps. "A rotating bridge spans the top, and a tube down the center holds the motor where some of the bearing temperature and motor amp measurements needed to be made. There are also two screws on the floor of the silo with motors that require temperature measurements. Conventional instrumentation proposed a huge challenge in this area." It was also a challenge for wireless, as the silos are made of a heavy gauge stainless steel with an additional metal skin for insulation.

Each of the nine conveyor belts had four bearing temperature measurements and four rub block temperature measurements that were handled by one 848T FOUNDATION™ Fieldbus High Density Temperature Transmitter.

SOLUTION

"We evaluated three technologies to determine the best course to improve safety at our plant," said Sorum. "The first was a conventional (4-20 mA) wired system, but it was too expensive to wire each instrument point to point." It also was not an option for the Weibull Bins because of the rotating bridge. The second solution was a wired bus. A bus solution would minimize home run wiring and lower the installed cost of the instruments while providing high performance and reliability. The third technology was a wireless network. This was considered mainly for the silos because of the rotating bridge.

Conveyor System

"We determined that FOUNDATION™ fieldbus provided the highest performance and reliability at the lowest installed cost," said Phelps. "Since one 848T FOUNDATION fieldbus Temperature Transmitter could handle all eight measurement points on a conveyor, we were able to handle 72 temperature points with only 9 transmitters." One 848T was installed for each of the nine conveyor belts, with each transmitter reading four bearing temperatures and four "rub block" temperatures. These points were integrated via fieldbus into the DeltaV control system to provide automatic detection, trending, and alarming of temperature, rate of change, and temperature delta for the operators. Integrating logic for the rub block temperature alarms was easy with the DeltaV tools. A function block template was used to design the complex logic and copied for all ignition points. Troubleshooting the logic was simple, as making a change to the template changed the function blocks for all ignition points.

One 848T Wireless Temperature Transmitter can handle up to 4 inputs including 4-20mA, mV, Thermocouple, RTD, or ohm. The field hardened enclosures and intrinsically safe Power Module makes it ideal for this hazardous environment.

Sugar Silos

Since the three Weibull Bins (sugar silos) had rotating equipment, a mixed solution of both *Wireless*HART® and wired instrumentation was installed. Each of the three silos had one Smart Wireless Gateway with four 648 (single point) Wireless Temperature Transmitters installed; two measuring bearing temperatures on motors and two measuring motor amps. Since the output of the motors is milliampere and the 648 transmitters read millivolts, it was a simple solution to put a 5ohm resister in the loop to get a millivolt output from each of the motors that the transmitters could read. Within each silo the four instruments formed a "communication mesh" that communicated with the Gateway. Since the outside of each silo was made of a heavy gauge stainless steel (with a thin metal skin and insulation), a remote antenna was placed inside the silo on the central rotating tube. This antenna was wired through the tube to the Gateway located on the outside of each silo. Each of the three gateways was hard wired back with ethernet to the DeltaV control system, where it was seamlessly integrated as "native I/O," and information was made available for trending and alarming. Installation time was minimized and commissioning was easy with the AMS Device Manager. "The AMS Device Manager was invaluable during installation and commissioning of the wireless and fieldbus instruments. Having one location to manage the devices saved a lot of time, as the instruments are spread all over the plant."

Four 648 (single point) Smart Wireless Temperature Transmitters were placed inside the silos to measure bearing temperatures and motor currents.

FOOD & BEVERAGE

Pond Management

ACS extended the use of Emerson's Smart Wireless technology to integrate non-critical points into the control room as well. Remote pond measurements were collected regularly to manually record pond levels, pH, ORP, dissolved oxygen, temperature and discharge flow rate. These conventionally wired devices were too expensive to bring back to the control room since the ponds were three quarters of a mile away or more. ACS realized the 848T had a wireless option as well as fieldbus, and could accept four inputs from any combination of RTD, thermocouple, ohm, millivolt and 4-20 mA signals. The analytical devices, ultrasonic flow devices, magmeters, and all other measurements from each of the 9 ponds were locally wired to the Wireless 848T Temperature transmitter and sent back to a Gateway and integrated into the control room environment where they could be automatically recorded, trended and reported. Two 702 discrete transmitters, acting as range extenders, were installed on 15 foot poles 0.54 miles from the furthest pond. The intent was to place the second device in series closer to the instrument mesh, but the network was able to communicate reliably at that distance. The second instrument therefore acts as a backup range extender to further improve communication reliability.

A remote antenna on the center rotating shaft inside the sugar silo allows the wireless instruments to communicate with the Smart Wireless Gateway located outside each silo.

Now wireless data is automatically collected at one minute intervals instead of twice weekly by operators. This rich information has helped ACS manage their ponds more closely, to make final treatment more efficient. It has also set the stage for new upcoming EPA reporting requirements, like proving the plant is meeting the new dissolved oxygen standard. Overall, the combination of *Wireless*HART and FOUNDATION fieldbus provided the most cost-effective solution for both critical and non-critical applications. The additional instruments widened the operator view into both hazardous and remote areas of the plant, and enabled engineering to improve plant safety. Operators spend their time more productively with fewer trips out to remote areas, and the plant is set up for new EPA reporting requirements. The Emerson solution has proven to be so valuable that ACS has installed it in all five sugar plants in the region.

RESOURCES

Emerson Process Management Food & Beverage Industry

http://www2.emersonprocess.com/en-us/plantweb/customerproven/pages/FoodBeverage.aspx

Rosemount 848T Temperature Solutions

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/High-Density-Measurement/Pages/index.aspx

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00830-0400-4848, Rev AB

PETROCHEMICAL | ROSEMOUNT AIS TEMPERATURE SENSORS

Chemical Plant Increases Process Availability and Product Quality with Multipoint Temperature Measurement

RESULTS

- Improved quality
- Increased process availability
- Reduced maintenance cost

APPLICATION

Acrylic Acid and Acrylic Esters reactor temperature measurement

Application Characteristics

Catalyst filled reactor with different layers

CUSTOMER

Chemical/Petrochemical plant in China

CHALLENGE

The chemical manufacturer was adding two Acrylic Acid / Acrylic Esters reactors to the plant site. Accurate temperature control is critical for quality and throughput from these reactors. If temperatures within the reactor are not accurately monitored and controlled, hot and cold spots can form.

The chemical manufacturer needed to make 40 different temperature measurements at 10 different levels within the reactor to monitor and control reactor temperature. Fast sensor response time and accurate, stable temperature measurement was required to effectively control the reactor temperature. High reliability was also required to minimize the risk of unplanned shutdowns. 40 separate process penetrations in the reactor would also introduce a high risk of leaks.

Hot spots can develop in the reactors leading to side reactions that create off-spec product and a ruined batch. Cold spots can slow the reaction so it will not run to completion, resulting in lower yields. Loss of temperature control can lead to an unscheduled shutdown reducing availability and yield. Single point measurements at each point would increase installation cost. Finally 40 separate process penetrations with single point instruments at each point would increase environmental risk and the ongoing cost of instrument maintenance.

Figure 1: Rosemount Multipoint Sensors

PETROCHEMICAL

SOLUTION

The challenges faced during the plant layout were solved with Rosemount Multipoint Temperature Sensors. Each sensor has 10 measurement points spaced to measure the temperature at each of the 10 levels of the reactor. This means a single process penetration at the top of the reactor replaced 10 process penetrations spaced over the entire reactor height. The 40 measurement points were accommodated with just four process penetrations. Five 848T temperature transmitters located near the top of the reactor accept the 40 temperature measurements. The long term stability and accuracy of the Compact Multipoint design resulted in reliable and stable performance of the temperature measurement in each of the layers. The fast response time of the Compact Multipoint design allows tight control of the process.

By using four Rosemount Compact Multipoint Temperature Sensors, installation and maintenance costs were reduced. The reduction in process penetrations also reduced the risk of environmental emissions.

The fast response time, accuracy, and stability of the temperature measurements reduced temperature fluctuations leading to higher quality and yield.

The combination of Rosemount Multipoint Temperature Sensors and 848T Temperature Transmitters has proven to be reliable, reducing the risk of unscheduled shutdowns.

Figure 2. Rosemount 848T Temperature Transmitter

RESOURCES

Emerson Process Management Chemical Industry

http://www.emersonprocess.com/solutions/chemical/

Rosemount Temperature

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx
http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

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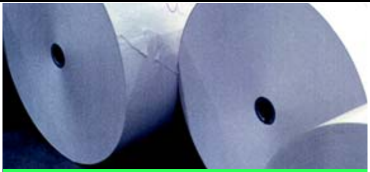
00830-0500-2654, Rev AA

PULP & PAPER | ROSEMOUNT 848T

Pulp and Paper Mill Saves on Installation Costs



RESULTS

- Saved 80-90% on wiring costs
- Improved integrity of critical temperature measurements
- Reduced maintenance costs and commissioning time

APPLICATION

Bearing and Winding Temperature Measurement

CUSTOMER

Pulp & Paper Mill in India

CHALLENGE

A major supplier of coated paper board and copier paper to the Indian market was installing a new cogeneration boiler. As part of the project they needed to monitor 80 bearing and winding temperatures in motors. In the past they had used 12-point scanning devices with local indicators, but with 80 points to monitor on the new boiler they preferred to display and monitor them at the control system.

The cost of running the 80 resistance temperature detectors' leads all the way to the control room or using locally mounted individual temperature transmitters with 4 -20mA two wire signals, however, was prohibitive. Multiplexors were an option, but the integrity of the signals was paramount - they were critical to the operation of the motors, the boiler and, ultimately, the plant itself.

SOLUTION

Emerson Process Management provided an answer with the Rosemount 848T Eight Input Temperature transmitter with FOUNDATION™ fieldbus output.

The engineers at the pulp and paper plant had never used fieldbus and were apprehensive. Emerson engineers demonstrated that with the H1 board in the control system, fieldbus could reliably carry the temperature data to the control room. As a bonus, they would have significant savings on installation, configuration and commissioning. The diagnostic functions would also reduce maintenance costs.

The diagnostic information made it possible to remotely determine a field device problem, saving costly trips to the field.

The Rosemount 848T accepts eight independently configurable sensor inputs and outputs the values on fieldbus. At this pulp and paper mill, the ten 848Ts, locally mounted, converted all eighty RTD temperature sensors to the fieldbus protocol so that just one fieldbus cable had to be run to the control room.

Fieldbus has proven that it can have dramatic benefits for end users. Wiring cost savings of 80-90% over conventional installations are being realized. The configuration and diagnostic information available in fieldbus devices greatly reduced commissioning time. The diagnostic information makes it possible to remotely determine a field device problem, saving costly trips to the field. For example, the Rosemount 848T provides continuous measurement status (good, bad or uncertain) as well as sensor failure indication.

The pulp and paper mill engineers were impressed by the advantages of fieldbus and the success of the project. They have since installed three more 848T transmitters and recommended the system on other projects within their company.

RESOURCES

Rosemount 848T

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Emerson Process Management's Pulp & Paper Industry Web Page

http://www.emersonprocess.com/solutions/paper/

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OIL & GAS

ROSEMOUNT TEMPERATURE AIS SENSORS

Gasification Process Downtime Reduced and Safety Improved with Application and Industry Solutions (AIS) Temperature Sensors

RESULTS

- Reduced unscheduled shutdowns
- Improved plant safety
- Improved throughput
- Reduced maintenance

APPLICATION

Gasification reactor temperature measurement

CUSTOMER

Synthetic crude oil producer in North America

CHALLENGE

This process uses bitumen from oil sands as a feedstock and converts it to synthetic crude oil using gasification technology. Gasification reactors operate at high pressure and temperature, with potentially dangerous gases such as hydrogen, and contaminants such as sulphur. Pressures of 65 bar or more (940 psi +), and temperatures of 1600 – 1800 °C (2900 – 3200 °F) are common. The gasification process works most efficiently at a target temperature so an accurate and reliable temperature measurement must be maintained in these very adverse process conditions.

Contaminants are present in the feedstock, and generated as part of the gasification process. These contaminants can become embedded in the precious metal temperature sensor elements and change the electrical and mechanical properties of the sensor. This can lead to measurement errors and sensor failure, sometimes within weeks. In addition, the contamination can degrade the integrity of the sensor seals. This can lead to mechanical failure of the sensor and the release of process contents into the plant.

Inaccurate temperature measurement can lead to reduced efficiency of the gasification process. Loss of the temperature reading can lead to using inferred temperature to control the reactor. This puts the integrity of the reactor, and therefore plant safety at risk. Loss of the temperature reading can also lead to a process shutdown and lost revenue. Finally, maintenance costs increase due to the need to frequently shut down the reactor, replace sensors, and restart the reactor.

Figure 1. Rosemount Sapphire Sensor

OIL & GAS

SOLUTION

A Rosemount Sapphire Sensor was used to address these challenges. The sensing element is surrounded by a sapphire protection tube. This sapphire protection tube is surrounded by a second ceramic tube. This dual tube design is highly resistant to penetration by contaminants even in these extreme process conditions. As a result the sensor electrical characteristics are not degraded, the sensor accuracy is maintained, and sensor life is extended from just a few weeks to 12 to 18 months. The Rosemount Sapphire Sensor also uses a dual sealing and the weldless connection head construction technique, which is highly resistant to mechanical failure. In the event that the inner sapphire tube is compromised, the dual seal system keeps the high temperature, high pressure process gases safely contained until the next planned process shutdown.

This solution brings many positive business results. Accurate temperature control is maintained leading to improved process efficiency. In addition, the risk of an over-temperature condition is reduced improving the integrity of the reactor and overall plant safety. The risk of sensor mechanical failure is also reduced improving plant safety. Throughput is improved due to reduced downtime and finally, operations and maintenance costs are reduced due to fewer shutdowns and reduced maintenance.

RESOURCES

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/index.html

Rosemount Application and Industry Solution Sensor

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

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00830-0700-2654, Rev AA

PHARMACEUTICAL TEMPERATURE

Pharmaceutical Company Saves Commissioning Time and Costs

RESULTS

- Wiring costs reduced by nearly 60%
- Reduce the risk of losing important temperature measurements by up to 80%
- Commissioning time reduced by nearly 60%
- Termination points reduced from 1,550 to approximately 150

APPLICATION

Reactor Temperature Measurement

CUSTOMER

Pharmaceutical company in India

CHALLENGE

Project engineers estimated that by using traditional sensor wire direct methods, the temperature points on the project would need approximately 1,550 terminations and commissioning would take about 30 days. Simple head mounted transmitters presented similar problems and multiplexers could not provide the integrity demanded of the 185 sensing points, especially the 45 that were critical. These critical points, where the process calls for very accurate and reliable measurement of the temperatures with a minimum of interruptions, were inside the reactor. These points also needed local indication.

SOLUTION

Emerson Process Management engineers developed a cost savings analysis comparing FOUNDATION™ fieldbus with traditional technology and presented it to the customer team. This provided the high integrity and low installation, commissioning, and operation costs the customer desired.

POWERS PlantWeb

Appreciating that the system offered reliability and technical advantages as well as savings, the customer purchased 16 Rosemount 848T and 32 Rosemount 3244 Temperature Transmitters. The 848T Temperature Transmitter accepts eight sensor inputs, and outputs the values onto fieldbus using a single cable. The multi-drop capability of fieldbus cuts wiring costs even further.

"We are very satisfied with the 3244 and 848T Temperature Transmitters. They have been working fine and trouble-free since commissioning and start-up."

Sr. Operation and Maintenance Manager

PHARMACEUTICAL

The ambient temperature limits and RFI immunity compliance of the field-hardened 848T allows it to be mounted close to process points under the most demanding operating conditions. As a result, the length of sensor cables run to each point is kept to a minimum, reducing installation costs by as much as 70% per point. In this case, 1,550 terminations were also reduced to approximately 150. Using the two-way communication capability of fieldbus, devices can be checked and configured from a convenient remote location. This feature reduces commissioning time by 60%. As a result, the customer completed commissioning in just seven days, less than a third of the estimated time.

The sensing points in the reactor, which required high integrity, were fitted with Rosemount 3244MV Temperature Transmitters, which also have a fieldbus output. The transmitters can warn operators and maintenance staff of sensor drift or failure by comparing inputs from two independent sensors. It also offers Hot Backup® which automatically switches to the backup sensor if the primary sensor fails. This feature reduces the risk of losing important temperature measurements by up to 80%.

With savings on cabling and two-way communication to the field devices, project engineers estimate a reduction of nearly 60% in cabling costs and commissioning time without compromising the integrity of the measurements. The fieldbus system not only fulfilled its promises of lower installation and commissioning costs, but also provides the customer with a state-of-the-art instrumentation and control package that is simple to maintain, operate, and develop.

NOTE: The Rosemount 3244MV Temperature Transmitter has been phased out and replaced by the Rosemount 3144P Temperature Transmitter.

RESOURCES

Rosemount 848T

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Rosemount 3144P

http://www.emersonprocess.com/rosemount/products/temperature/m3144p_ff.html

Emerson Process Management's Life Sciences Industry Web Page

http://www.emersonprocess.com/lifesciences

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METALS & MINING | ROSEMOUNT AIS SENSORS

Furnace OEM Increases Throughput with Application and Industry Solution (AIS) Sensors

RESULTS

- Reduced maintenance costs by reducing calibration cycles
- Improved throughput

APPLICATION

Temperature measurement in a high tech annealing furnace

CUSTOMER

A global furnace manufacturer

CHARACTERISTICS

- Oven temperature from 1000 °C up to 1270 °C, depending on batch material
- Frequent change of batches
- 20-30 measurements over an 80 meter long furnace

CHALLENGE

This customer is an OEM of annealing furnaces and provides turnkey installation services. The temperature measurement of the annealing furnace is very critical for the quality of the stainless product that goes through it. Thermocouple performance checking should be fast, easy, and error-free.

Maintenance and operation personnel need full information at this rough environment, with ambient temperature ranging from 40 °C - 55 °C near the furnace. They used wire-direct rather than transmitters in temperature measurement. During maintenance, these thermocouples were removed from the furnace and calibrated in a bath once a month.When these thermocouples were reinstalled, sometimes the polarity was reversed, causing measurement errors and disrupting operations.

Due to these measurement errors the annealing furnace needed to be shutdown, affecting production. Maintenance costs also increased due to the frequent need to check the furnace performance and correct the reversed polarity problem.

This solution is so successful, it's the standard way the OEM installs thermocouples on all their furnaces shipped worldwide.

Figure 1. Rosemount AIS sensor

Rosemount Application and Industry Solution (AIS) High Temperature Type S Thermocouples ranging from 20 to 30 pieces were installed on two furnace units on top and bottom measuring points to improve temperature control. These thermocouples have ceramic protective tubes to increase their long-term stability in high temperature environments and have compensating cables and connector plugs. Two 644H with LCD (local display) were mounted remotely into a housing with socket available for the connecting plugs and housing close to the furnace. The connector plugs cannot be plugged in incorrectly, so reverse polarity occurrences when replacing the thermocouples were eliminated.

Rosemount AIS sensors helped improve the performance of the maintenance team. Less faults and less time consumption lead to reduced maintenance costs. It also made installation and commissioning easy. Throughput was increased due to eliminating the production time lost while fixing reversed thermocouples. This solution is so successful, it's the standard way the OEM installs thermocouples on all their furnaces shipped worldwide.

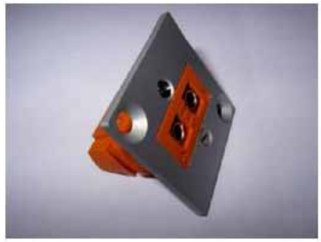

Figure 2. Connector Plug

Rosemount Application and Industry Solution Sensors

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

Rosemount 644 Head and Rail Mount Temperature Transmitters

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/Single-Point-Measurement/644/Pages/index.aspx

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OIL SANDS ROSEMOUNT 848T

High Density Temperature Measurement Saves Capital Costs on Upgrader Expansion Project

RESULTS

- Decreased capital expenditure
- Reduced the risk of damage to capital equipment
- Improved plant safety
- Reduced the risk of unplanned shutdowns

APPLICATION

Skin temperature monitoring of pipes, vessels, and pumps

Application Characteristic: Oil upgrader unit operating temperatures ranging from 1000 to 1300 °F.

CUSTOMER

A North American oil sands upgrader

CHALLENGE

This customer needed to monitor the skin temperature throughout its upgrader facility. The design of the facility included more than 3,000 temperature measurements to reduce the risk of thermal shock to their newly installed operating equipment.

Safety restrictions required that every piece of equipment in this unit be brought up to the operating temperature prior to startup, in order to prevent thermal shocking of the piping, pumps, vessels, and other mechanical parts. The instrumentation used in the expansion needed to be compatible with the legacy host system infrastructure, and provide a cost effective architectural solution.

This customer wanted to avoid unnecessary capital and operational costs in their new facility. A traditional point-by-point temperature architecture would be cost prohibitive for this customer's expansion project. Furthermore, plant wide protection of personnel and capital equipment were a priority to ensure safe operations, and to reduce the risk of unplanned shutdowns.

The high density architecture provided by the Rosemount 848T reduced capital costs related to installation and materials.

Rosemount 848T

OIL SANDS

SOLUTION

Emerson installed 242 Rosemount 848T FOUNDATION™ fieldbus High Density Temperature Transmitters. This solution enabled a significant cost advantage, and was easily integrated into the legacy host system. The 848T transmitters were used for 2,000 of the 3,000 total temperature points. They measure eight temperature points with one device, reducing the amount of wiring needed to communicate the measurements to the host system.

For the remaining 1,000 single point temperature measurements, the Rosemount 644 and Rosemount 3144P Temperature Transmitters were installed based on the critical nature of the application.

The high density architecture provided by the 848T reduced capital costs related to installation and materials. The technology and ease of implementation built into the 848T protected capital equipment from damage associated with thermal shock. Finally, risks related to safety and unplanned shutdowns were minimized due to the added visibility to plant operations.

RESOURCES

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Rosemount 848T Products Data Sheet

http://www.emersonprocess.com/rosemount/document/pds/4697b00n.pdf

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WASTEWATER TREATMENT — ROSEMOUNT AIS SENSORS

Stopford Projects Ltd., Achieves Consistent End-Product Quality with Multipoint Application and Industry Solution (AIS) Temperature Sensors

RESULTS

- Consistent quality of end-product
- Increase energy efficiency
- Reduce safety risk

Application and Industry Solutions (AIS) temperature sensor met all requirements which resulted in more efficient and safer operation of the waste treatment system.

APPLICATION

Temperature measurement of an on-site thermal desorption system

APPLICATION CHARACTERISTICS

Multipoint temperature measurements at different heights with single process entry

CUSTOMER

Stopford Projects Ltd., United Kingdom

CHALLENGE

The Matrix Constituent Separator (MCS™) is a safe, low-cost, on-site desorption process that turns contaminated waste to inert solids and provides recovery of hydrocarbons. The instrument engineer of this engineering design and project management company was having difficulty in identifying the trend of the batch process and optimizing the batch control.

The system had no equipment to measure the temperature of the batch it is processing. Adjustments in the batch process to meet the desired end-product quality were made manually and didn't necessarily provide the desired result.

The uncertainty in temperature of each batch resulted in varying quality of decontamination leading to inefficient energy usage due to excessively high temperatures during decontamination. Furthermore, if the temperature of the thermal desorption process goes beyond a certain point, a fire could occur leading to costly equipment damage and safety risk to the operator. If the temperature is too low, the waste may not break down enough for safe inert landfill.

Figure 1. Installed Rosemount Multipoint Application and Industry Solution (AIS) sensor

Rosemount Multipoint Temperature Sensors with four temperature points within one insert have been installed at designated lengths. These sensors are directly wired to the process and a PLC receives and records the temperature measurement and activates an alarm in case of high temperature. Rosemount Multipoint Temperature Sensors have compact design and can be replaced on-site for easy maintenance. In addition, Rosemount's vast experience in temperature solutions ensured the right sensors were selected for the application.

By installing the multipoint sensors, they are able to record the batch trend and optimize batch control, thereby increasing efficiency of the process. This further resulted to consistency in end-product quality, recovering 99% of hydrocarbons and meeting the hazardous landfill legislation by breaking down the waste to landfill safe soil. Finally, a high temperature alarm enables a shut down of the process if temperatures exceed preset levels, ensuring safe operation.

Figure 2. Rosemount Multipoint sensors

Emerson Process Management Water & Wastewater Industry

http://www.emersonprocess.com/solutions/water/

Rosemount Application and Industry Solution Sensors

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

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STEEL SMART WIRELESS

Steel Mill Decreases Operating Costs and Reduces Environmental and Safety Risks with Smart Wireless

RESULTS

- Decreased operations and maintenance costs
- Reduced environmental and safety risks
- Improved coke quality

APPLICATION
Coke oven temperature

CUSTOMER
Steel mill in North America

CHALLENGE
This steel mill was having problems controlling the temperature in their coke ovens. It is crucial to stay within the coke oven operating limits. Low temperatures risk oven collapse and capital damage. High temperatures waste heat and increase utility costs.

Because of high wiring cost this steel mill initially had no measurement on their coke ovens and required measurement rounds twice every shift. The customer tried implementing a wireless technology in this application, but the technology was unreliable due to battery life and moving larry cars. The long communication distance increased the power consumption and therefore decreased the battery life to a couple of months. Also, the wireless technology was point-to-point and the larry cars regularly blocked the signal path, causing communication to be unreliable.

Not having a reliable coke oven temperature measurement negatively impacted this customer's business. Routine measurement rounds increased operations and maintenance costs. It also made an environmental impact and increased the safety risks of personnel. When the lids to the coke ovens were opened to make manual measurements, coke oven emissions were released into the atmosphere. The carcinogens and the high oven temperatures increased the safety risks of its operators. Lastly, the quality of coke exiting the oven was diminished when it did not operate at the correct temperatures.

The customer experienced an improvement in coke quality because it could reliably control the coke oven temperatures.

The Rosemount 848T Wireless

STEEL

SOLUTION

The Rosemount 848T Wireless High Density Temperature transmitter solved the challenges this customer faced. The 848T wireless transmitter utlizes SmartPower™ technology, which provided a longer battery life for this application. It improved battery life from months to years. Also, the self-organizing network provided greater than 99% data reliability and was not affected by the larry cars.

This customer utilized the best core technology, implementation practices, and field intelligence within the Rosemount 848T Wireless High Density Temperature Transmitter to positively impact their business. The customer decreased operation and maintenance costs because they no longer had to perform measurement rounds twice every shift. Environmental and safety risks were also reduced because the coke oven doors never had to be physically opened by an operator, exposing them to the emissions or intense heat. Lastly, the customer experienced an improvement in coke quality because it could reliably control the coke oven temperatures.

RESOURCES

Smart Wireless

http://www.emersonprocess.com/smartwireless/

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/index.html

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OIL & GAS | ROSEMOUNT TEMPERATURE AIS SENSORS

Gasification Plant Decreases Process Downtime and Increases Efficiency with Rosemount Sapphire Sensor

RESULTS

- Significantly decreased process downtime
- Improved efficiency of process
- Decreased damage to refractory brick lining

APPLICATION
Gasification of solid carbon fuels

CHARACTERISTICS
Operating temperature and pressure at 1538 °C (2800 °F) and 42 bar (615 psi)
Slag and contaminants formation causing premature thermocouple failure

CUSTOMER
Gasification plant in the U.S.

CHALLENGE
This gasification plant needed to frequently service their gasifier as its refractory brick usually cracks due to excessive heat. Their optimization engineer and reliability engineer needed to improve the efficiency of the gasifier and make it more reliable to avoid process shutdowns to repair the unit.

Additionaly contaminants in the fuel source caused premature failure of the thermocouples previously in use. Prior to failure, the thermocouple would report temperatures that can be several hundred degrees cooler than the actual temperature due to the effect of contamination of the thermocouple wires causing variations of the mV signal. As a result, the temperature of the gasifier reaches in excess of 1760 °C (3,200 °F) causing the refractory brick, lining to crack.

Having a poor control on the process temperature meant that they needed to run the gasifier hotter than necessary. This frequently resulted in a cracked refractory brick, leading to unscheduled shutdown to replace the failed sensor and to repair the damaged brick. In addition, the plant burned more fuel due to the faulty readings of the thermocouples.

Sapphire high temperature sensor enabled the gasifier to run more efficiently and operate for longer periods between maintenance cycles with fewer major repairs despite challenging application environment.

Figure 1. Rosemount AIS Sapphire High Temperature Sensor

ROSEMOUNT

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OIL & GAS

SOLUTION

To solve the problem, the engineers decided to install a Rosemount AIS Sapphire high temperature sensor. The sapphire protection tube incorporated into the Sapphire Sensor protects the thermocouple from contamination, ensuring accurate temperature readings throughout its useful life. Since the thermocouple is no longer subject to contamination, it lasts significantly longer than other high temperature thermocouples. Furthermore, the Sapphire Sensor has a dual sealed head providing added comfort by ensuring that process gases will not leak into the ambient environment.

By improving the temperature measurement, the optimization engineer enabled the gasifier to run more efficiently and use less fuel. It also allowed the reliability engineer to make the gasifier operate for longer periods between maintenance cycles with fewer major repairs to the refractory lining required. And ultimately, it decreases the unnecessary process shutdown, saving valuable operations time.

Figure 2. Sapphire Sensor Cutaway

RESOURCES

Emerson Process Management Oil and Gas Industry

http://www.emersonprocess.com/solutions/oilgas/index.asp

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/index.html

Rosemount Application and Industry Solution Sensor

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

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NATURAL GAS DISTRIBUTION ROSEMOUNT 848T

National Natural Gas Distributor Reduces Project Cost and Improves Reliability with Improved Temperature Measurement

RESULTS

- Reduced project cost
- Shortened project schedule
- Improved reliability
- Improved measurement accuracy

Enagas reduces project cost and improves reliability with Rosemount 848T temperature monitoring.

APPLICATION

Surface temperature control in tanks and pipes

CUSTOMER

Enagas, the national natural gas distributor for Spain

CHALLENGE

Enagas is implementing a multi-year plan to reduce cost and improve speed of project execution. As part of a plant expansion, Enagas needed to implement cost effective temperature measurement on storage tanks, boiloff tanks and pipes. Some of the measurements were cryogenic.

In an earlier project phase, Enagas installed 3-wire PT100 RTD's wired to a multiplexer in the control room to monitor temperatures in two tanks. The combination of long wire runs and multiplexers suffered from noise and measurement instability. If one RTD had a problem, all the RTD's were affected. This compromised the measurement accuracy. Enagas needed to solve the problems on the installed measurement points, and find an accurate, reliable and cost effective solution for the remaining two tanks.

The measurement errors increased cooling costs and caused excess natural gas boiloff. Correcting the problem by retrofitting with 4-wire RTD's would have resulted in high project cost and a lengthened project schedule for Enagas.

Figure 1. Rosemount 848T FOUNDATION™ fieldbus Temperature Transmitter

NATURAL GAS DISTRIBUTION

SOLUTION

Enagas replaced the multiplexers in the control room with Rosemount 848T FOUNDATION fieldbus temperature transmitters. This solved the noise and instability problems they were experiencing on the first two tanks.

The transmitters on the remaining tanks were installed close to the tanks and pipes to shorten sensor wiring lengths. The number of wires run from the process to the control room for the remaining tanks was reduced over 95% using the Rosemount 848T.

The solutions provided by the Rosemount 848T resulted in substantial business benefits for Enagas. The 848T temperature transmitters delivered a 2 °C improvement in accuracy. This led to lower cooling costs and reduced boiloff.

In addition, the 95% reduction in wires to the control room for the remaining two tanks significantly reduced project time and cost. The faster project execution and lower cost Enagas achieved moved them closer to achieving their overall improvement goals.

RESOURCES

Rosemount Temperature

http://www.emersonprocess.com/rosemount/products/temperature/index.html

Rosemount 848T Products Data Sheet

http://www.emersonprocess.com/rosemount/document/pds/4697b00n.pdf

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PETROCHEMICALS EMERSON SMART WIRELESS

Petrochemical Plant Drives Energy Efficiency with Smart Wireless DP Flowmeters and Temperature Transmitters

RESULTS

- Higher efficiency
- Lower operations costs
- Lower capital costs
- Fast, easy installation

APPLICATION

Natural gas flow to a gas metering grid

CUSTOMER

Petrochemical plant in India producing Linear Alkali Benzene (LAB)

CHALLENGE

Energy efficiency is an important operations consideration in the process industries. Reducing energy cost is an imperative in today's environment. Operations personnel wanted to measure the plant's consumption of natural gas and have tighter control over the gas metering grid to drive efficiency and reduce operating cost.

To achieve this target, gas flow needed to be measured at the steam source and temperature measured at the gas metering grid respectively. The plant's layout resulted in some challenging physical limitations. For instance at the heater and boiler system, a traditional orifice plate could not be installed due to limited straight run availability. At the gas metering grid, it was not economical to layout cables to wire the temperature transmitter to the central control room. Furthermore, there were no available empty slots for additional analog input (AI) cards at the Distributed Control System or DCS, preventing additional data integration into the DCS without a capital expenditure.

Without means to measure process parameters, engineers were unable to have tighter control of the process. They could not tell if the boiler and heater were consuming too much gas, resulting in an inefficient process and increased energy cost. Installing traditional measurement devices would incur high project cost and could affect the production schedule due to the need for pipe preparation and wire trenching.

The wireless solution brought critical operations data such as flow rate, gage pressure and process temperature, to the control room enabling engineers to tighten and improve process efficiency.

Wireless gas flow measurement with Rosemount 3051SFC and THUM was easily integrated into the plant DCS.

PETROCHEMICALS

SOLUTION

The plant called on Emerson Smart Wireless capabilities to address the project limitations. Six Rosemount 3051SFC Conditioning Orifice Flowmeters with THUM adapters were installed to measure gas flow into the boiler and heater systems. The 3051SFC requires a shorter straight pipe run with its Conditioning Orifice Technology. It also has fewer leak points as it eliminates impulse lines, and is leak tested at the factory to ensure fast and easy installation between existing flanges. For the gas metering grid, two Rosemount 648 Wireless Temperature Transmitters were installed. This provided immediate temperature measurement without worrying about wiring costs. These field devices were wirelessly integrated to the existing DCS through a Smart Wireless Gateway.

The wireless solution brought data such as flow rate, gage pressure and process temperature to the control room which is critical to operations. This made gas consumption visible to the process engineers enabling them to make adjustments and make the process more efficient. The ease of installation also made the project easier to execute. And lastly, with the wireless network in place, the plant now has more flexibility to explore other measurement points.


A Rosemount 648 Wireless installed in the Gas Metering Grid.

RESOURCES

Emerson Process Management Chemical Industry

http://www2.emersonprocess.com/en-US/industries/Chemical/Pages/index.aspx

Emerson Smart Wireless

http://www2.emersonprocess.com/en-US/plantweb/wireless/Pages/WirelessHomePage-Flash.aspx

Rosemount Conditioning Orifice Flowmeters

http://www2.emersonprocess.com/en-US/brands/rosemount/Flow/DP-Flow-Products/Conditioning-Orifice-Flowmeter/Pages/index.aspx

Rosemount Temperature

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/Pages/index.aspx

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POWER ROSEMOUNT 848T

Energy Company Complies to New Mercury Removal Emission Regulations Without Compromising Project Cost by Using Smart Wireless

RESULTS

- Compliance with Federal and State Regulations
- Reduced project cost
- Minimized environmental risk
- Reduced safety and health risk of nearby communities

Rosemount 848T Wireless Transmitter enabled this energy company to meet government mandated law without compromising on project cost.

APPLICATION

Temperature measurements of boiler boxes

CUSTOMER

Energy company located in Western, USA

CHALLENGE

All coal fired plants are being required to reduce mercury emissions under federal regulatory rules by November 2010. This energy company planned to comply with the law by implementing a system which would reduce their mercury emissions without incurring high project cost.

One way to reduce mercury emissions is to introduce chemicals that will help mercury in coal to be water soluble. The first step is to spray calcium bromide onto the coal which will react with mercury to form mercury bromide. Then, inject activated carbon upstream of the air pre-heater to grab mercury bromide and allow a flue gas desulfurization (FGD) scrubber to remove it. This process needs accurate and reliable temperature measurements at the back of the boiler box since mercury conversion works better at specific temperatures.

Uncontrolled mercury emissions have many adverse effects; one is raising the risk of polluting the environment. Another is risking the health and safety of nearby communities. Furthermore, if found not complying with the law, this energy company risks penalties and damages to their reputation.

SOLUTION

Efficient mercury removal requires that the temperature across the entire back of the boiler box be within a specific temperature range. A complete temperature profile across the back of the boiler box is needed. Several multi-point Rosemount 848T wireless temperature transmitters were installed at the same level on each boiler box. These were then wirelessly connected to a single DCS to provide the desired temperature profile monitoring. This installation proved cost effective as it eliminated the cost of running conduit and wires to each sensor.

Rosemount 848T Wireless Temperature Transmitter

POWER

Rosemount 848T Wireless Temperature Transmitter enabled this energy company to meet the new mercury emission removal regulation, avoiding fines and penalties while saving an approximate 40,000 USD in project cost by going wireless. Most importantly, the 848T played a key role in a control system with which they were able to lower mercury levels in their flue gas, reducing risk to the environment and the health and safety of nearby communities.

RESOURCES

Emerson Process Management Power Industry

http://www.emersonprocess.com/solutions/power/index.asp

Rosemount Temperature

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/Pages/index.aspx

Emerson Smart Wireless

http://www2.emersonprocess.com/en-US/brands/rosemount/Wireless/Pages/index.aspx

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GLASS ROSEMOUNT AIS SENSORS

Fiberglass Manufacturer Improves Maintenance Cycle and Product Quality with High-Temperature Thermocouple

RESULTS

- Improved fiberglass quality
- Increase process availability
- Decreased energy cost

APPLICATION

Temperature measurement in a high tech annealing furnace

CHARACTERISTICS

- Air temperature of 2372 to 2912 °F (1300 to 1600 °C)
- Molten glass temperature of 2372 to 2912 °F (1300 to 1600 °C)

CUSTOMER

A leading fiberglass manufacturer in Asia

CHALLENGE

This fiberglass manufacturing plant needed to control temperature of hot air to maintain smooth flow of molten glass in the glass furnace. Proper temperature of hot air is crucial to achieve desired quality of end product.

Exposed to a highly corrosive environment, the temperature sensors usually start to fail, sending out unstable temperature reading. Operators needed to frequently change sensors to ensure that the temperature of hot air and molten glass was within range.

Due to sensor failure, the process needed to be stopped, causing delay to production and unavailability of the glass furnace. Unstable temperature reading caused increased fuel consumption as the glass furnace was adjusting to the incorrect temperature measurement. Furthermore, molten glass temperature was not maintained leading to defects in the final product.

Rosemount high-temperature thermocouple is better protected for extremely harsh process conditions reducing maintenance cycle and limiting unplanned shutdown due to sensor failure.

Rosemount 1075 High Temperature Thermocouple

GLASS

SOLUTION

The plant installed two Rosemount 1075 high temperature thermocouples to replace the failed sensors. The first element is measuring the natural gas temperature at about 1440 degrees C and has ceramic protective tubing. Meanwhile, the second element has a platinum protective tube used for the molten glass temperature measurement at about 1370 degrees C. This provided a highly accurate and stable temperature reading over along period of time, improving the sensor replacement cycle. The expected life span of the sensor is above seven years.

With the temperature of the molten glass properly maintained, the end product quality desired is achieved. And since the Rosemount high-temperature thermocouple is better protected for extremely harsh process conditions, the frequency of replacing failed sensors was decreased, leading to an improved maintenance cycle and limiting unplanned shutdown. Finally, the plant was able to save on fuel consumption of the glass furnace due to better temperature control brought by accurate and reliable temperature measurement.

RESOURCES

Rosemount Application and Industry Solution Sensors

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

Rosemount 1075 High-Temperature Sensors

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/1075-High-Temperature/Pages/index.aspx

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ROSEMOUNT

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00830-1200-2654, Rev AA

REFINING ROSEMOUNT AIS SENSORS

MOL Danube Refinery Increases Throughput and Quality of Sulfur Recovery by Improving Process Efficiency

RESULTS

- Improved sulfur recovery and tail gas quality
- Reduced operating cost by improving process efficiency
- Reduced maintenance cost

APPLICATION

Claus Process Thermal Reactor

MOL Danube Refinery is planning to implement the solution to its other recovery units with the same expected improvement and savings.

APPLICATION CHARACTERISTICS

- Extremely corrosive acid gas environment that may contain very high sulfur oxides, hydrogen, sulfides, chlorides, acid gases, ammonia, etc.
- 1,380 °C (2516 °F) at max with significant temperature changes during the process 200-300 °C (392-572 °F).

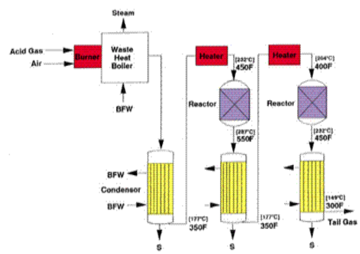
CUSTOMER

MOL Danube Refinery in Százhalombatta, Hungary

CHALLENGE

MOL Danube Refinery is the largest oil refinery in Hungary. They are utilizing a Claus Process to recover sulfur from feed acid gas to ensure compliance to environmental regulations. The plant's maintenance engineer wanted to increase the process efficiency by improving throughput, quality, maintenance, and operating cost.

Accurate temperature measurement is critical in the desulfurization process as it will affect the recovery output and tail gas quality. There are a total of four temperature measurement points in the burner chamber. Two points monitored by conventional ceramic high-temperature sensors and the other two points by pyrometers. The conventional sensors with DIN Form A aluminum connection head and inside/outside ceramic protective tube cracked easily due to very fast temperature changes occurring in just minutes. This exposes the sensor to high concentration of sulfur oxides, hydrogen, sulfides, chlorides, and other acid gases causing thermocouple wire contamination leading to sensor failure. Replacement cannot be done immediately after a sensor fails as the desulfurization process can only be shutdown once per year.



Claus Sulfur Recovery Plant

ROSEMOUNT

For more information:
www.rosemount.com

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REFINING

With only the pyrometers left to monitor the process temperature after the conventional ceramic sensor fails, the accuracy of the measurement was affected. This led to increase energy usage as the burner is running higher than the optimum process temperature. Recovery throughput and tail gas quality was impacted as well since accurate temperature measurement is critical in the process.

Claus Recovery unit with a Rosemount Application and Industry Solution (AIS) Sapphire Temperature Sensor

SOLUTION

The maintenance engineer replaced the failed conventional sensor of one Claus Recovery unit with a Rosemount Application and Industry Solution (AIS) Sapphire Temperature Sensor. The initial test showed that the sapphire sensor with its patented sapphire protective tubing lasted longer compared to just four to six weeks of the conventional sensor. This showed it was more successful in this harsh process condition, withstanding abrupt temperature changes, high gas corrosion, and contamination.

Since the sapphire sensor lasted longer, it resulted in more accurate temperature monitoring, enabling MOL Danube Refinery to meet their target sulfur recovery content and further increase tail gas quality. The burner is now running longer on its optimum temperature resulting to better energy use, leading to improve process efficiency. And with the sapphire sensor still working for over 12 months, maintenance does not need to do replacement of failed sensors during process shutdown, which was common in the past. This allowed them to save on maintenance cost. Having this positive test outcome, MOL Danube Refinery is planning to implement the solution to its other recovery units with the same expected improvement and savings.

RESOURCES

Emerson Process Management Refining Industry

http://www2.emersonprocess.com/en-US/industries/refining/Pages/index.aspx

Rosemount Application and Industry Solution Sensors

http://www2.emersonprocess.com/en-US/brands/rosemount/Temperature/AIS-Sensors/Pages/index.aspx

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00830-1300-2654, Rev AA

REFINING | TEMPERATURE

Bearing Monitoring Prevents Costly Refinery Shutdowns

RESULTS

- Prevented costly unscheduled shutdowns
- Reduced installation costs by up to 70%
- Increased data reliability
- Improved diagnostic capabilities

The control system, now with improved diagnostic capabilities, identified a damaged bearing. This helped prevent an unscheduled shutdown.

APPLICATION

Bearing temperature monitoring on recycling gas compressor

Application Characteristics: 16 thermocouples, 200 meters (656 feet) to control room, electromagnetic interference, Modbus® control system

CUSTOMER

Refining company in South Asia

CHALLENGE

A South Asian refining company needed to monitor bearing temperature to prevent costly shutdowns of their hydrocracker. They had local temperature monitoring, but they did not have a way to monitor and record temperature data at or near their Modbus control system.

The bearings were located in the recycling gas compressor, 200 meters away from the control room. If the refinery could get the highly important diagnostic data into the control room along with their existing vibration monitoring system, they could effectively monitor and maintain their compressor.

SOLUTION

The refinery engineer decided that given the long cabling distance and likelihood of RFI, transmitters would be a better solution than the previously considered direct Modbus wiring. Emerson provided two Rosemount 848T multi-point temperature transmitters to locally collect the bearing temperature. The transmitters were then connected to a Rosemount 3420 Fieldbus Interface Module. The interface allowed the FOUNDATION™ fieldbus protocol transmitters to easily communicate with the Modbus control system. It also provided the additional benefits of a digital signal.

Compressor Control Panel

The combination of Rosemount devices allowed the refinery to send the data back to the control room using an existing 2-conductor cable. The flexibility in protocols and the reliable temperature monitoring capability significantly reduced the number of unplanned shutdowns and saved over 70% in wiring costs at the same time. In this case, due to additional trenching, the savings amounted to $20,000.

The bearing temperature measurement system has already proven its worth. At 2:30 pm one afternoon, not long after the monitoring system had been put into operation, an operator switched the recycled gas compressor to manual. To increase production, he reset the operating speed from its normal 10% to 95%. He was unaware, however, of the damaged condition of one of the compressor's bearings. The increased speed could lead to the bearing's failure which would shut down the compressor and, as a result, the complete process.

The control system, now with improved diagnostic capabilities, identified a damaged bearing. The operator quickly switched the unit back to normal operation, saving the bearing and preventing a costly and unnecessary shutdown. By preventing an emergency shutdown, the refinery was able to replace the bearing during scheduled maintenance. The advanced warning minimized both the materials and the repair time necessary for equipment failures.

RESOURCES

Rosemount 848T

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Rosemount 3420

http://www.emersonprocess.com/rosemount/products/accessories/m3420.html

Emerson Process Management's Refining Industry Web Page

http://www.emersonprocess.com/solutions/refining/

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EMERSON Process Management

00830-3100-4697, Rev BA

REFINING

Smart Wireless Minimizes Capital Costs for Online Monitoring of Plant and Instrument Air

RESULTS

- 73% savings in CAPEX costs
- Reduced plant downtime with live trending of compressor data
- Saved over $50,000 per year in operations costs

APPLICATION

Wireless air compressor monitoring

CUSTOMER

A major refinery in North America

CHALLENGE

This refinery installed two new compressors to maintain the reliability of plant and instrument air. Unfortunately, the buildings that house the compressors and control room are very old. The only way to wire was to pull cable under the road between the buildings. Access above ground was unavailable due to the dense infrastructure of equipment. “We only have nine measurements, but wiring was a logistical nightmare”, said the Systems Engineer in charge of the project. “A wired option would have cost over $135,000. It just was not an option.”

The refinery needed a cost effective solution to continuously monitor pressure, temperature, and flow of compressed air going to both the plant air system and the instrument air supply system. Online measurement would ensure timely intervention if air flow was interrupted, and also would provide information necessary to monitor the efficiency of the compressors.

SOLUTION

This customer purchased nine Smart Wireless instruments. The wireless instruments included Rosemount pressure and temperature transmitters, and DP flowmeters to monitor the new compressors. Due to the dense infrastructure of both buildings, a remote antenna for the Smart Wireless Gateway was placed on top of the building that housed the control room to optimize reliability of communications. Emerson’s Wireless Field Network was integrated into the legacy host via Modbus™ over ethernet protocol.

Now operators can continuously monitor the health of the compressors from a remote location, and will automatically get an alarm if the efficiency of the compressors begins to decrease, or if there is a loss of pressure or flow.

“We only have nine measurements, but wiring was a logistical nightmare. A wired option would have cost over $135,000. It just was not an option”.

Systems Engineer
Major North American Refinery

AMS Wireless SNAP-ON Application

REFINING

Loss of compressed air can have a significant impact on the plant, and early detection will prevent process downtime and compressor failure. Not only does wireless provide early warning, but it provides a historical trend of pressure, temperature and flow.

Instead of three manual readings per day, each Smart Wireless instrument updates the control host every minute for a historical trend of nearly 1500 points per day. That means operators can spend their time doing more productive tasks instead of travelling to the compressors every shift. Also, the high resolution of data makes troubleshooting compressor problems much easier.

This customer received the AMS® Wireless Configurator and purchased the AMS Wireless SNAP-ON™ to enhance monitoring of the wireless network. The AMS Suite predictive maintenance application provides real-time access to wireless data from any engineering console. This gives system engineers full access to the Smart Wireless instrument data, and also shows them the communication paths of each instrument. "The AMS Wireless SNAP-ON allows us to monitor and verify path stability of each instrument through the entire mesh network," said the Project Engineer. "In fact, when an obstruction interrupted the network I watched live as the mesh network groomed itself and automatically reorganized, without interruption to any of the nine instrument signals."

The wireless solution represented a 73% savings over the wired option, and enabled live trending of compressor data, which decreased plant downtime. Since the wired solution was cost prohibitive, the only alternative was manual readings once a shift. If operator time is valued at $50/hr., the plant saved over $50,000 per year in labor costs. This does not include the value of live trending and alarming to prevent process downtime. Overall, the Smart Wireless Network has improved reliability of the plant and instrument air supply, and enabled operators and systems engineers to work more productively.

"The AMS Wireless SNAP-ON allows us to monitor and verify path stability of each instrument through the entire mesh network. In fact, when an obstruction interrupted the network, I watched live as the mesh network groomed itself and automatically reorganized without interruption to any of the nine instrument signals".

Systems Engineer
Major North American Refinery

RESOURCES

Emerson's Smart Wireless

http://www.EmersonSmartWireless.com

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00850-0100-4180, Rev AA

CHEMICAL

Chemical Manufacturer Avoids Shutdowns by Using Fieldbus Technology

RESULTS

- Avoided chemical reactor shutdown
- Estimated cost savings of $1.5 million in lost production
- Avoided labor and material costs associated with unplugging the reactor

The Rosemount 848T and 3420 provided an efficient, cost-effective solution.

APPLICATION

Monitoring reactor temperature during polymerization process

CUSTOMER

A North American chemical manufacturing company

CHALLENGE

It is typical to carefully monitor the transition of a chemical reactor during start-up with a process designed to run at constant steady state conditions. In this case, a chemical manufacturing company was preparing to start up one of its production trains for a particular product type. Precise control of the operating conditions was necessary to regulate the polymerization process to produce on-spec product.

To observe the progress of the reaction during start-up, the customer wanted to monitor the temperature profile of the reactor's dome. Any indication of the temperature moving outside the normal limits could indicate that polymerization was occurring in the wrong stage of the reaction. This could create a solid polymer plug in the reactor, which could cause a unit shutdown. If the reactor were to plug, it could cost the customer anywhere from two to three weeks in downtime, depending on the severity of the plugging or polymerization. Lost production for this unit is estimated at approximately $3000 per hour of downtime. This number does not include the labor and material costs that would be required to unplug the reactor.

SOLUTION

The project team first evaluated a traditional approach using individual transmitters on 16 temperature sensors. Because of the long wire run and high installation costs, the project was not funded. However, when the team learned of the Rosemount 848T Eight Input temperature transmitter and its potential wiring cost savings due to the FOUNDATION™ fieldbus

CHEMICAL

technology, they quickly realized they had a cost-effective alternative. They also used the Rosemount 3420 Fieldbus Interface Module because their 5-year-old TDC DCS did not have fieldbus capability, but a Modbus Serial interface was available. The cost of the 848T/3420 solution was about 50% of the traditional analog installation.

The instrumentation used in this application consisted of two 848Ts and one 3420. Sixteen Type J thermocouple assemblies with magnetic pull downs were installed at each required temperature monitoring point. The sensor lead wires were run to a nearby 848T with each transmitter accepting eight sensor inputs. The 848Ts are mounted in a junction box and wired to a fieldbus terminal block. A single pair of wires is run from the 848Ts to the 3420, which is located about 650 feet away in the control room where they are then interfaced to the DCS.

This cost effective temperature monitoring solution proved beneficial to the customer during start-up. The 848T and 3420 enabled the customer to notice an increase in temperature on the dome of the reactor during start-up. Upon entering the reactor, plastic buildup on the inside of the dome was identified. Without these extra monitoring points, the problem would not have been identified early enough to avoid a shutdown. The customer estimated a savings of approximately $1.5 million in lost production.

The Rosemount 848T installed.

RESOURCES

Rosemount 848T

http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Rosemount 3420

http://www.emersonprocess.com/rosemount/products/accessories/m3420.html

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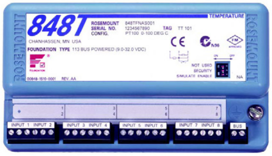
PHARMACEUTICAL ROSEMOUNT 848T

Rosemount Temperature Transmitters Prove Best Practice on Project in India

RESULTS

- Termination points reduced from 1,550 to approximately 150
- Wiring costs and commissioning time reduced by nearly 60%
- High integrity temperature measurement of critical sensing points



APPLICATION

Reactor Temperature Measurement

CUSTOMER

Atul LTD, Gujarat, India

CHALLENGE

Project engineers working on the Pharma Intermediate Project at the Atul Limited chemical complex were investigating solutions for their temperature measurement. They estimated that by using traditional sensor wire direct methods, the temperature points on the project would need approximately 1,550 terminations and commissioning would take about 30 days.

Simple head mounted transmitters presented similar problems and multiplexers could not provide the integrity demanded of the 185 sensing points, especially the 45 that were critical.

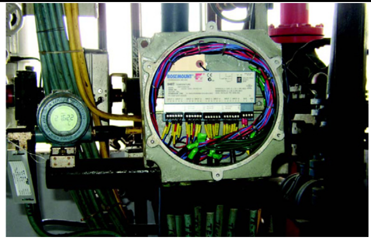
The critical points where the process calls for very accurate and reliable measurement of the temperatures with a minimum of interruptions were inside the reactor. These points also needed local indication.

The project attracted bids from several suppliers of instrumentation and control equipment. Emerson Process Management offered a DeltaV™ system with field instruments but the Atul Project Engineering Team felt that the overall price was too high and that the critical nature of the measurements, especially those in the reactor, were not adequately addressed.

"We are very satisfied with the 3244 and 848T Temperature Transmitters. They have been working fine and trouble-free since commissioning and start-up."

Ketan Shah
Sr. Operation and Maintenance Manager

PHARMACEUTICAL



A Rosemount 3244 MV and 848T installed in the field.

SOLUTION

Emerson Process Management engineers, however, recognized the potential savings and integrity that FOUNDATION™ fieldbus could offer to the project. Engineers from the Measurement and Control divisions worked together. Drawing on the experience gained on many FOUNDATION™ fieldbus systems operating around the world, they developed a cost savings analysis comparing FOUNDATION™ fieldbus technology with traditional technology and presented it to the Atul Project Engineering Team.

Rosemount 848T Multipoint Temperature Transmitters and Rosemount 3244 MultiVariable (MV) Temperature Transmitters, using a FOUNDATION™ fieldbus communication link to the DeltaV™ control system, provided the high integrity and low installation, commissioning, and operation costs the Atul engineers were looking for.

The Atul project team factored the savings into the overall project cost. The overall costs were then far lower than the alternatives offered. Appreciating that the system offered reliability and technical advantages as well as savings, the Atul engineers accepted the proposal. They purchased 16 Rosemount 848T and 32 Rosemount 3244 Temperature Transmitters.

Installation and Commissioning

The 848T Temperature Transmitter accepts eight sensor inputs, and outputs the values onto FOUNDATION™ fieldbus using a single cable. The multi-drop capability of FOUNDATION™ fieldbus cuts wiring costs even further.

Ambient temperature limits and R.F.I immunity compliance of the field-hardened 848T allows it to be mounted close to the process point under the most demanding operating conditions. As a result, the length of sensor cables run to each point is kept to a minimum, reducing installation costs by as much as 70% per point. In this case, 1,550 terminations were also reduced to approximately 150.

Using the two-way communication capability of FOUNDATION™ fieldbus, devices can be checked and configured from a convenient remote location. This feature reduces commissioning time dramatically. As a result, the customer completed commissioning in just seven days, less than a third of the estimated time.

Critical Sensing Points

The sensing points in the reactor, which required high integrity, were fitted with Rosemount 3244MV Temperature Transmitters, which also have a FOUNDATION™ fieldbus output.

The Rosemount 3244MV transmitter can warn operators and maintenance staff of sensor drift or failure by comparing inputs from two independent sensors. It also offers Hot Backup which automatically switches to the

PHARMACEUTICAL

backup sensor if the primary sensor fails. This feature reduces the risk of losing important temperature measurements by up to 80%.

With savings on cabling and two-way communication to the field devices, project engineers estimate a reduction of nearly 60% in cabling costs and commissioning time without compromising the integrity of the measurements. The FOUNDATION™ Fieldbus system not only fulfilled its promises of lower installation and commissioning costs, but also provides the customer with a state-of-the-art instrumentation and control package that is simple to maintain, operate, and develop.

NOTE: The Rosemount 3244MV Temperature Transmitter has been phased out and replaced by the Rosemount 3144P Temperature Transmitter.

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GLASS INDUSTRY

Glass Furnace Temperature Upgrade Saves $31,000 and Reduces Maintenance

RESULTS

- Saved $21,000 in labor costs
- Saved $10,000 in material costs
- Reduced calibration frequency
- Improved accuracy and process throughput

APPLICATION

Glass furnace temperature monitoring and control

CUSTOMER

Manufacturer of glass products in North America

CHALLENGE

The manufacturer upgraded 12 vapor deposition furnaces which they use to produce high quality glass products. The re-instrumentation of these processes was done in an effort to improve product quality, increase product throughput, and lower their overall operating costs.

The temperature application on each furnace consists of 16 monitoring points, eight non-critical control points, and one critical control point. Four furnaces are located in an area of about 200 feet end-to-end, and each temperature sensor measurement is an average of 150 feet from the DeltaV™ I/O cabinet.

"The transmitters were easy to install... changing thermocouple types has been a piece of cake. Things have been up and running very well since startup."

Supervisor of Control Engineering and Information Technology

SOLUTION

The manufacturer selected the Rosemount 848T Eight Input Temperature Transmitter to communicate the thermocouple measurements. The measurements were used to monitor and control the non-critical air, oil, and water zone temperatures at different locations throughout the furnace. Each transmitter uses eight Analog Input (AI) function blocks to communicate the measurements on the fieldbus segment.

The Rosemount 3244MVF Temperature transmitter is used to control the inlet temperature of the raw material. Due to the critical nature of this measurement, the manufacturer used the 3244MVF's Hot Backup®, Transmitter-sensor Matching, and Sensor Drift Alert features to improve accuracy and process throughput.

GLASS INDUSTRY

The Sensor Drift Alert feature tells the manufacturer when the critical temperature control point requires recalibration. Each 3244MVF uses two AI's, one PID, and one Input Selector (ISEL) function block along with the Backup Link Active Scheduler feature. As a result, the manufacturer estimates that the 848T and 3244MVF transmitters save them 940 man-hours per year due to reduced calibration frequency. This translates to approximately $21,000 annually.

For the temperature monitoring application, the manufacturer compared an 848T installation against wiring the thermocouples directly into the DeltaV thermocouple I/O cards. They chose to use the 848T for this project because it was a more cost-effective solution. They were able to connect existing sensor wiring to the transmitters to simplify their wiring and significantly reduce installation costs.

The manufacturer estimates that the 848T solution saved them $10,000 on the re-instrumentation of the 12 vapor deposition furnaces. The savings were realized by using the 8484T on the Flouride Crystal process that had a very high concentration of expensive thermocouple wire. The wide variety of sensor input types and ability to accept eight sensors per transmitter provided significant savings by using the Rosemount 848T.

The Supervisor of Control Engineering and Information Technology at the plant said, "The 848T offered us a very clean solution for our temperature monitoring application. The 848Ts were easy to configure... changing thermocouples has been a piece of cake. Things have been running very well since startup. To date, the 848T solution has been supplying us with very accurate results." He is now looking at leveraging his experience with the 848Ts on the vapor deposition furnace and applying it to new processes in the plant.

Note: The Rosemount 3244MVF Temperature Transmitter has been phased out by Emerson and replaced by the Rosemount 3144P Temperature Transmitter

RESOURCES

Rosemount 848T
http://www.emersonprocess.com/rosemount/products/temperature/m848t.html

Rosemount 3144P
http://www.emersonprocess.com/rosemount/products/temperature/m3144p.html

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00850-0300-4697 Rev BA

SMART WIRELESS APPLICATIONS

PlantWeb® Architecture Provides Flexible Automation Solution for Pilot Ethanol Processing Plant in Sweden

BENEFITS

- Implementation of advanced process automation technology places Chematur Engineering at the forefront of process plant design
- Flexible network architecture makes it easy to modify, develop and expand plant
- Common user interface provides “clean” front end
- Hands-on experience pinpoints suitable future applications for wireless

CHALLENGE

A pilot ethanol processing plant was built by Chematur Engineering in Karlskoga, Sweden to demonstrate its unique ‘Biostil®’ production process and for customers to trial the latest process automation technologies with their specific raw materials. Regular plant modifications for client specific demonstrations created a requirement for a flexible networking architecture. Another requirement was a user friendly interface for easy access to all plant control and monitoring including predictive diagnostic information.

SOLUTION

PlantWeb® digital plant architecture has been implemented with the DeltaV™ digital automation system controlling the entire plant from a single operator station. Using advanced networking functions, process data is placed in the hands of the operator, improving efficiency.

A wireless field network based on Emerson’s *Wireless*HART™ devices enables process monitoring of various sections of the plant. Nine Rosemount® wireless pressure transmitters and seven wireless temperature transmitters deliver measurements of water, slurry (water, yeast and starch/sugar mixture) and the final product ethanol. A further 30 instruments communicate process control and asset management information using FOUNDATION™ fieldbus.

“A plant wide wireless network offers enormous benefits by bringing the control room out into the plant. Placing this kind of power in the hands of operators produces much greater worker efficiency. For maintenance and especially during commissioning and start-up phases wireless becomes an excellent tool.”

Johan Selinder
Manager, Electrical & Control Design
Chematur Engineering AB

SMART WIRELESS APPLICATIONS

A wireless plant network consists of a rugged wireless access point providing high bandwidth connectivity to a touch tablet PC. The touch tablet PC incorporates DeltaV and AMS® Suite asset management applications and is used as an operator-station in the field as well as a replacement for local indicators on the field instruments.

AMS Wireless SNAP-ON™ is used to maintain the wireless network. This application graphically displays the communication paths, diagnostic and performance parameters to prevent potential problems with the field instruments.

RESULTS

The implementation of advanced process automation technology places Chematur Engineering at the forefront of process plant design. The flexible network architecture makes it easy to modify, develop and expand the plant, with Smart Wireless enabling temporary installations, and changes of transmitter location without the need for re-engineering.

Hands-on experience has helped Chematur Engineering get an understanding of where wireless technology can be successfully applied. Currently it sees the benefits in monitoring applications accessing data from remote or difficult to reach parts of the plant.

Emerson's AMS Suite provides a common user interface for easy access to predictive diagnostic information from the FOUNDATION fieldbus and *Wireless*HART devices. The real-time device information provided allows operators to respond faster and make informed decisions. It also helps to achieve a faster start-up and when the plant is running it can increase its availability through more cost-effective maintenance and improved device performance.

"Currently we see the benefits of wireless in monitoring applications accessing data from remote or difficult to reach parts of the plant. Installing cabling in these places can be cost prohibitive, especially if there are just one or two instruments to be connected."

Johan Selinder
Manager, Electrical & Control Design
Chematur Engineering AB

Nine Rosemount wireless pressure transmitters and seven Rosemount wireless temperature transmitters have been installed.

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SMART WIRELESS APPLICATIONS

Environmental Compliance Simplified with Smart Wireless Solutions

BENEFITS

- Wireless solutions enable easier way to report temperature and pressure measurements associated with combustion engines
- Integration with company's business network allows data to be logged remotely
- Cost-effective solution enables better compliance with local regulations

CHALLENGE

Many midstream gas processing facilities have compressor stations which utilize internal combustion engines that are regulated by local environmental agencies for emissions compliance. They are required to monitor and report the inlet temperature and differential pressure across a catalyst that burns harmful chemicals prior to being released into the air. If they are not compliant with the environmental regulations, they face large fines that can accumulate over time.

SOLUTION

Emerson proposed a Smart Wireless solution to monitor the inlet temperature and differential pressure across the exhaust catalyst. These measurements are made with the Rosemount 648 Wireless Temperature Transmitter and Rosemount 3051S Wireless Pressure Transmitter, which report their measurements every 15 minutes. The customer's engineers decided they could integrate the data with the company's business Ethernet network through the Smart Wireless Gateway. This allowed the company to easily log data remotely.

RESULTS

Emerson provided a reliable and cost-effective wireless solution that reduced the total installed cost, including wiring and labor. In this particular situation, there was a shortage of qualified electricians, so reducing the installation time was a key benefit. By integrating the measurement data into the business Ethernet network, environmental engineers were allowed to pull measurement data from the system to create standard reports for the environmental agency. This reduced the amount of time spent generating the report. Now the environmental engineers can spend more time analyzing the data to predict potential problems, resulting in lower fines and cost-effective compliance with local regulations.

For more information:
www.EmersonProcess.com/SmartWireless

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Network Helps Bord Gáis Monitor Gas Transmission Pipeline System in Ireland

BENEFITS

- Redundant wireless network ensures data integrity despite the site being divided by a public road
- Cable integrity issues in Ex areas removed thereby reducing the number of site inspections required

"Smart Wireless is ideal for site upgrades where instruments and cabling can be up to 25 years old and in need of replacing. Installing the transmitters is very simple as the wireless devices simply replace the existing analog devices."

Frank Smiddy
Communications & Instrumentation Engineer
Bord Gáis

CHALLENGE

As well as supplying gas and electricity to the Irish market, Bord Gáis, the state owned energy provider is also responsible for the maintenance and upkeep of the countries natural gas distribution network. Bord Gáis has a Mains Renewal Programme in place to ensure that the pipeline system is the most modern in Europe. As part of the renewal programme, a remote Above Ground Installation (AGI) located at Middleton, near Cork, was to undergo an upgrade of its hard wired instrumentation. Power and data cabling are usually installed in ducting at the AGIs to protect them from the environment and from external damage. However, burying cables can prove to be costly and time consuming. The Middleton site has an added challenge in that it is divided by a public road, requiring additional trenches to bury the cables.

Bord Gáis decided to explore the possibility of installing a network of wireless pressure and temperature transmitters at the site in order to reduce the installation costs, but without affecting data integrity. Although there is minimal traffic on the road dissecting the site, it was felt that a line of sight wireless solution could not be used as the signal may be interrupted by passing cars affecting the reliability of the communications.

SMART WIRELESS APPLICATIONS

SOLUTION

Rosemount® wireless transmitters, including five measuring pressure, one differential pressure, and one temperature have been successfully installed and are sending measurements back to the control room via the onsite Remote Terminal Unit (RTU).

The devices are placed in enclosures, standard practice for all instrumentation used at Bord Gáis AGIs, and the Smart Wireless Gateway is positioned within the instrumentation kiosk, which is effectively a "walk-in" enclosure.

RESULTS

For the upgrade at Middleton, Emerson's Smart Wireless plant network promised to cost less than a traditional wired installation, offered faster installation and start up, and easy integration into the existing RTUs using Modbus serial communications. The Smart Wireless devices have redundant communication to the RTU via two or three routes thereby overcoming the problem of signal interference by cars. Where cabling enters into a potentially explosive EX Zone, regular checks are required of cable integrity as well as the condition of the EX barriers. With no wires or EX barriers, the number of site inspections required has been reduced.

"Reliability has not been an issue. Enclosures do not interfere with the wireless signals at all and we trend the transmissions from the control room so we can see if there are any problems. So far there haven't been any."

Brid Sheehan
Communication & Instrumentation Engineer
Bord Gáis

Rosemount wireless devices are placed in enclosures, standard practice for all instrumentation used at Bord Gáis' AGIs.

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Technology Improves Throughput By Up to 10% at AOC's California Resins Manufacturing Facility

BENEFITS

- Secure, self-organizing wireless network eliminates clipboard rounds
- Staff safety improved by continuously monitoring resin batch temperatures

CHALLENGE

AOC is a leading global supplier of resins, gel coats, colorants, and additives for composites and cast polymers. AOC was looking for a solution to ensure proper mixing of intermediate resin products with micro-additives at target temperatures to achieve customer-specific formulations and quality.

SOLUTION

Eight Rosemount® wireless temperature transmitters continuously check batch temperatures, sending that real-time data to a Smart Wireless Gateway integrated with the plant's DeltaV™ digital automation system. The company uses Emerson's AMS® Suite predictive maintenance software to manage the devices, which enables technicians to configure them, run diagnostic checks, and monitor alarms and alerts.

AOC chose reliable Smart Wireless technology because it required minimal wiring, the wireless transmitters can easily be moved from one location to another, and it was more cost-effective than wired technology. Set up and commissioning of the network was quick and easy, taking only 12 hours.

RESULTS

Emerson Process Management's Smart Wireless technology is continuously monitoring resin batch temperatures at AOC's Perris, California facility to enable better process control with up to 10% improved throughput, and increased employee safety.

Smart Wireless eliminated clipboard rounds that were an inefficient use of operators' time, subjected personnel to a safety risk, and lengthened the time to market. If staff found the temperature was not at target, it required additional time and resources to heat or cool the mix tank to the target temperature before adding temperature dependent micro-additives or loading the product. By replacing manual sampling with on-line measurements, AOC was able to decrease cycle time up to 10 percent. They also improved operator safety, and freed up staff time to improve other areas of the plant.

"By replacing manual sampling with on-line measurements, we were able to decrease cycle time up to 10 percent. We also improved operator safety, and freed up their time to improve on other areas of the plant."

Tou Moua
Product Engineer, AOC

SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Products – Using Open *Wireless*HART™ Standard – Significantly Improve Production at StatoilHydro Gullfaks Offshore Platforms

BENEFITS

- Automated solution provides flow measurements every 30 seconds
- Early detection of loss of flow now possible
- Improved throughput and over time significant increases in production
- Number of manual measurements in hazardous areas reduced

CHALLENGE

StatoilHydro was occasionally losing flow from the producing wells at its Gullfaks A, B and C platforms, caused by a loss of wellhead pressure. No flow-metering devices are installed so temperature readings are used to detect loss of flow. Typical well fluid is 60° C so the pipe feels warm, but should flow be interrupted the pipe drops back to the ambient temperature. However, the manual readings taken by an operator placing a hand on a pipe were only collected at the start and end of a shift, so flow interruption could easily go undetected for long periods and production would be lost. An automated solution was required but the wellhead was already a very crowded area and for safety reasons the introduction of additional equipment such as new cabling, cable trays and junction boxes was not possible. Wireless presented an obvious solution but with metal pipe work, walkways above and below, and many other metal obstructions, a line of sight wireless solution could not offer the reliability of connection required.

"Emerson's wireless transmitters have enabled the quick and reliable detection of lost flow, and the immediate action taken to re-establish flow has increased production significantly."

Tormod Jenssen
Staff Engineer, Plant Integrity, Gullfaks Field, StatoilHydro Norway

SMART WIRELESS APPLICATIONS

SOLUTION

StatoilHydro initially implemented a pilot installation of Emerson's Smart Wireless technology on the Gullfaks A, B & C platforms. Rosemount® 648 wireless temperature transmitters were installed, providing an indication of flow at forty wells. The wireless devices are used to transmit data from clamp-on temperature sensors mounted on the surface of the flow pipes. In contrast with the once-a-shift manual recordings, Emerson's Smart Wireless devices now transmit readings back to the existing control system every 30 seconds providing operators with the real time information they need to react quickly to any change in flow.

Despite the difficult working environment and the lack of line of sight between the transmitters and the gateway, there were no connection problems. The `plug and play' nature of Smart Wireless made it easy to install and to quickly establish a connection with newly installed devices.

RESULTS

Early detection of the loss of flow is enabling operators to rebuild the pressure and quickly start the flow again, improving throughput and significantly increasing production over time. An automated solution is helping to improve safety as the need for personnel to enter this hazardous area is reduced. StatoilHydro has now implemented additional Smart Wireless devices on Platforms A, B and C, bringing the total to 90 wireless transmitters covering all production flow lines at Gullfaks.

"Installing additional wired measurement points at the wellhead would mean long cable trays and a lot of wiring. Wireless offers an inherent reduction in cabling infrastructure, complexity and weight, resulting in significantly lower installation costs."

Anders Røyrøy
Project Manager, Research & Development Projects, StatoilHydro Norway

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SMART WIRELESS APPLICATIONS

Smart Wireless Network Assures Bitumen Pipeline Stays Hot During Ship Unloading at Terminals Pty Ltd in Australia

BENEFITS

- Wireless was selected for its lower initial cost and minimal maintenance compared with hard wiring
- Smart Wireless instruments monitor heat-tracing on pipeline which must be hot to facilitate pumping
- Readings are sent to AMS Suite predicitive maintenance software for instrumentation configuration and performance monitoring

CHALLENGE

Terminals Pty Ltd needed a reliable solution to monitor temperatures in a 900-meter-long 8-inch (200mm) heat-traced pipeline used for unloading bitumen from ships at its Geelong Terminal in Australia. It is necessary to make certain the electric heaters are operating all along the pipeline to keep the bitumen hot (160°C) and fluid. If a heater fails, a cold spot could form causing the bitumen to solidify and plugging the line with expensive consequences.

SOLUTION

Emerson's Smart Wireless technology was selected for its lower initial cost and minimal maintenance as compared with hard wiring. Eight Rosemount® wireless temperature transmitters are evenly spaced along the pipeline, sending temperature readings on one-minute intervals to a Smart Wireless Gateway on shore that channels data to the AMS® Suite predictive maintenance software used for instrument configuration and performance monitoring. The collected data are also forwarded to a SCADA system in the terminal control center via fiber-optic cable.

"We needed to monitor the bitumen line to make the operators aware of cooling anywhere in the line from the ship to the storage facility, which could result in an emergency shutdown. Any delay in unloading could keep a ship at the pier longer than planned with demurrage costing up to $30,000 US per day."

Joe Siklic
Bitumen Terminal Project Manager
Terminals Pty Ltd

SMART WIRELESS APPLICATIONS

RESULTS

Due to the self-organizing nature of this technology, each wireless device acts as a router for other nearby devices, passing the signals along until they reach their destination. If there is an obstruction, transmissions are simply re-routed along the mesh network until a clear path to the Smart Wireless Gateway is found. All of this happens automatically, without any involvement by the user, providing redundant communication paths and better reliability than direct, line-of-sight communications between individual devices and their gateway. This self-organizing technology optimizes data reliability while minimizing power consumption.

This is an ideal application for wireless. Since numerous paths exist to carry the transmissions, the network would easily compensate for a transmitter failure, and the operators would be warned. This wireless network has proved to be reliable, compatible with existing control equipment, and cost effective. The amount of structure on the wharf is minimal, and that is another benefit.

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SMART WIRELESS APPLICATIONS

Smart Wireless Solution Increases Throughput of Rotating Kiln

BENEFITS

- Wireless devices reliably and cost-effectively measure temperature on rotating lime kiln
- Installation took less than one day to complete
- Operation of Lime Kiln accounts for increased throughput by 5%

CHALLENGE

A pulp and paper mill struggled to properly control calcining in a lime kiln. To do this the customer needed to measure the internal temperature on a rotating lime kiln. Due to the restrictions of wiring, this measurement was inferred, decreasing throughput of the kiln.

SOLUTION

The customer purchased two Rosemount 648 Wireless Temperature transmitters with thermocouples and a Smart Wireless Gateway. The customer requested shipment as soon as possible, and all items were on site in a matter of days. The sensors were installed on opposite sides of the kiln's mid-zone, 180 degrees apart. The temperature transmitters were mounted on a pipe that extends away from the kiln. This installation took less than one day to complete. Temperature updates are sent to the control room through the gateway.

RESULTS

Since the installation, the mill is enjoying improvement of throughput with this kiln. The inferred temperatures were found to be off by 350° F. The Smart Wireless solution circumvented the constraints of the rotating kiln and made the measurements possible.

"Four days after the order was placed we could see minute-by-minute mid-zone temperatures trending on the control system ... Since the wireless system has been installed, we can tell if there's build-up of lime in the mid-zone area. Overall, we have improved operation of the lime kiln, and increased throughput by 5%."

Pulp Mill Leader

For more information:
www.EmersonProcess.com/SmartWireless

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Solutions Protect Remote Pumping Facilities at Milford Power

BENEFITS

- Smart Wireless solution communicates easily in dense environment with many obstructions
  - All 12 devices were communicating within 2 hours
  - Wireless communication was not interrupted when new building was erected in the middle of the network
- Smart Wireless helps prevent freeze damage to water pumping and circulation equipment
- Wireless saved $75,000 in installation and capital costs

CHALLENGE

Milford Power, a 500 MW gas-fired turbine facility in Milford, Connecticut, utilizes two gas-fired turbines to produce electricity for the grid. The site includes eleven remote buildings that house water pumping and circulation equipment serving a variety of needs of the power generation infrastructure. Since winter brings freezing conditions, small heaters are located in each remote building to ensure the pumps operate properly. Freeze damage of a pump system would cost $10,000 to $20,000 to repair or replace and take that pump out of commission for up to three days. They wanted to find a technology to bring temperature measurement into the control room as part of an early warning system. Wiring of these points was not feasible, since running trays over the roads or conduit under existing structures was cost prohibitive.

SOLUTION

Milford Power installed Rosemount 648 Wireless Temperature Transmitters in all eleven remote buildings around the plant. The devices then communicated through a Smart Wireless Gateway back to the control room.

RESULTS

Damage to the water pumping and circulation equipment was prevented by monitoring the temperature with Smart Wireless solutions from Emerson. An early warning detection system for rapid temperature change was achieved, at a fraction of the cost of a wired solution.

"We looked at various technologies and selected the Emerson... Especially important was the easy, flexible self-organising network that could be installed and operational in a very short time...this is an excellent solution that works well, is easy to install and very easy to expand..."

Cliff Esmiol
Maintenance Supervisor, Milford Power

For more information:
www.EmersonProcess.com/SmartWireless

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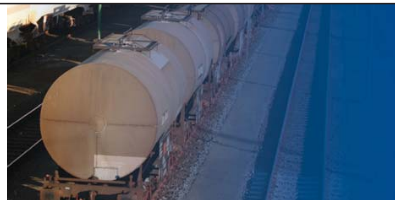
SMART WIRELESS APPLICATIONS

Emerson Wireless Technology Safely Monitors Temperatures in Railcars at Croda Inc.

BENEFITS

- Provides cost-effective method to continuously monitor rate of rise for product temperatures
- Installation of the self-organizing network is fast and easy
- Employees no longer need to climb to the top of the railcars every day



"There are savings of $14,000 per year in reduced operations and maintenance costs, but, the incalculable savings were in safety."

Denny Fetters
I&E Designer, Croda Inc.

CHALLENGE

Croda requires large amounts of a chemical for the production of intermediates for hair and skin care products, non-active pharmaceutical ingredients and household and industrial cleaners. The chemical is brought on site by 24,000 gallon capacity railcars. At any one time, three railcars are kept on the perimeter of the plant and one is positioned at the service station for off-loading as required. Since the chemical is a highly reactive and flammable chemical, it is critical to monitor internal temperatures. Contaminants left over from rail car cleaning or unintentionally introduced in other ways can lead to an uncontrolled exothermic reaction, with potentially catastrophic results if neutralization procedures are not implemented in a timely fashion.

There was no practical and cost effective method to continuously monitor rate of rise for product temperatures and assure that a reaction was not taking place. Since the railcar positions are subject to change, hard wiring was not practical. An employee needed to check temperatures on each railcar on a daily basis. This involved climbing on top of each railcar and checking the internal temperatures and recording the information. This was a time consuming and somewhat dangerous procedure during inclement weather.

SOLUTION

Since rate of rise temperature monitoring on railcars was labor intensive and potentially dangerous, this chemical customer was an early adopter of Rosemount's wireless technology. The release of this wireless self organizing network provided the plant with continuous monitoring of railcar temperatures from the control room. Railcar position changes have no effect on the network since it is self organizing, and line of site is not required for each car. Information from each of the 648 wireless temperature transmitters, placed on each railcar as they arrive, is communicated through the 1420 gateway back to the control system via modbus. While operators look for temperature excursions, transmitter

SMART WIRELESS APPLICATIONS

performance is simultaneously monitored by maintenance through an AMS station.

Installation of the self-organizing network is fast and easy, which is important since railcars are continuously entering and leaving the facility.

RESULTS

Employees no longer climb to the top of the railcars every day, and the operators have early detection for temperature excursions. The customer estimated savings of $14,600 per year in reduced operations and maintenance costs. Implementation of a wireless solution not only saved time and labor but greatly enhanced the overall safety of the plant and personnel.

"Emerson's wireless solution not only saves us time and money, since plant personnel no longer have to monitor those railcars daily, it has also greatly enhanced the overall safety of the plant and our personnel. We are pleased with the performance of the Rosemount® transmitters and Emerson's self-organizing wireless network. No matter where a railcar is positioned on-site, the quality of the transmissions is unaffected, and the signals integrate seamlessly into our control system."

Denny Fetters
I&E Designer, Croda Inc.

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SMART WIRELESS APPLICATIONS

Emerson Smart Wireless Transmitters Monitor River Water Temperatures at Lenzing Fibers

BENEFITS

- Improved the reliability and availability of the measurements meeting local government environmental regulations
- Wireless network eliminated the need for costly trenches
- Reduced operations costs by eliminating the number of trips to the river

CHALLENGE

Lenzing Fibers is the world's largest producer of Tencel® fibers. The Heiligenkreuz fibers plant uses water drawn from a local river for cooling purposes. Local environmental regulations require that the water returned to the river must not be more than 3 degrees Celsius higher than the water extracted, and that the company must maintain a constant check and record of the water temperature at both inlet and outlet points. Prior to the regulation being introduced, Lenzing was already monitoring the water temperatures manually involving daily visits to the river. However to meet the environmental regulation there was a need to improve the reliability of the results and for these measurements to be easily stored and be made readily available for inspection.

An online measurements solution was required, but because of the distance of the River Lafnitz from the control room and the fact that the public are free to walk by the river, it would have been necessary to dig a trench for the cabling and this would have been very expensive.

"We would have had to dig a trench for the cabling which would have been very expensive. The cost of installing wireless is much lower and has made this project possible."

Wolfgang Gotzi
Head of Automation and Maintenance Department, Lenzing Fibers

SOLUTION

Emerson Process Management's Smart Wireless technology has been successfully applied to monitor river water temperatures. The temperature of the water extracted from the river is transmitted wirelessly via Emerson's Rosemount® wireless temperature transmitter, to a Smart Wireless Gateway. The gateway is positioned on an external wall of the pump station control room, 200 meters away. A second wireless transmitter is installed where water is returned to the river, and a third transmitter is 200 meters downstream where it measures the temperature of the remixed water after the return point.

SMART WIRELESS APPLICATIONS

The Smart Wireless network is integrated into Lenzing Fibers' existing control system and the temperature information is stored in a data historian in order to meet the requirements of the environmental regulations. Emerson's AMS® Suite: Intelligent Device Manager is used to manage the new Smart Wireless devices, enabling the technicians to configure the devices, run diagnostic checks and monitor alarms and alerts. AMS Suite is also used to manage and store calibration information.

RESULTS

Emerson's Smart Wireless has provided a cost effective and highly reliable online measurement solution, enabling the company to reduce operations costs by eliminating the number of trips to the river and to streamline reporting, thereby meeting local government regulations related to the temperature of water discharged into rivers and watercourses.

"The Emerson technology was both easy to install and integrate and has been extremely reliable in terms of data transfer. We are currently looking at other applications where Smart Wireless can be applied."

Wolfgang Gotzi
Head of Automation and Maintenance Department, Lenzing Fibers

Emerson's Smart Wireless solution monitors river water temperature at the Lenzing Fibers mill.

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4-09

SMART WIRELESS APPLICATIONS

Smart Wireless Technology Helps CalPortland Company Comply with Air Quality Regulations at California Cement Plant

BENEFITS

- Self-organizing wireless network reliably monitors cement kiln's NOx emissions reduction process despite rotating equipment and harsh conditions
- Enables compliance with quality emissions requirements
- Installation of the devices completed in one day

CHALLENGE

The gradually-sloped 540-foot-long, 13-foot-diameter kiln rotates almost twice a minute and operates at temperatures as high as 2,800° Fahrenheit. The company uses a Selective Non-Catalytic Reduction (SNCR) process of spraying ammonia into the kiln to control NOx emissions. It needed to monitor the temperature of the ammonia, the process gases as well as the kiln's slight vacuum. It had tried using a slip ring around the kiln to check these parameters but frictional wear ground down the ring and the growth of the kiln as it heated up broke insulators isolating the process signal.

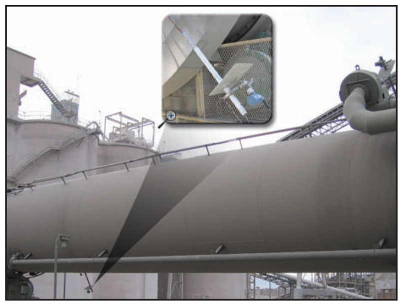
SOLUTION

The CalPortland installation includes Emerson's self-organizing wireless network of field instrumentation that reliably monitors the process used to reduce NOx emissions inside a rotating cement kiln at the facility. NOx is a byproduct of the pyro process involved in the chemical procedure of cement manufacture.

The wireless network includes four of Emerson's Rosemount® wireless temperature transmitters, one wireless DP transmitter, and a Smart Wireless Gateway. CalPortland chose wireless because it was the best solution that could meet the very challenging application. "The rotation, extreme temperature, and the location of the kiln (at 20 to 40 feet above grade), made using a wired solution impractical," said Steve Tyrrell, CalPortland senior electrical supervisor.

"By installing this wireless network, we were able to monitor and treat the NOx in the kiln successfully when there was no other alternative."

Steve Tyrrell
Senior Electrical Supervisor, CalPortland



Emerson's Smart Wireless technology reliably monitors the process used to reduce NOx emissions inside a rotary cement kiln at CalPortland's cement plant.

SMART WIRELESS APPLICATIONS

RESULTS

The installation of the four devices onto the kiln was completed in one day. The DP transmitter was installed on the injection shroud to measure the extremely low vacuum inside the kiln. The temperature transmitters were installed at different locations around the kiln.

The self-organizing network transmits signals reliably to a Smart Wireless Gateway despite the fact that devices are installed at opposite sides of the kiln. The line-of-sight view is blocked at times between some devices and the gateway but no data has been lost. The gateway is integrated with the facility's existing PLC control system.

By installing Emerson's Smart Wireless network, CalPortland was able to monitor and treat the NOx in the kiln successfully when there was no other alternative, and enabled them to comply with the NOx emissions regulations and improve control over the process.

"With a rotary kiln, the continued addition of process variable instrumentation to optimize the control strategy becomes overwhelming. The wireless option allowed for movement of the process indicators to various positions on the kiln for development of the control strategy."

Steve Tyrrell
Senior Electrical Supervisor, CalPortland

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SMART WIRELESS APPLICATIONS

Smart Wireless Technology Improves Productivity of Rotating Kiln at Russian Alumina Plant

BENEFITS

- Reliable temperature measurement
- Off-spec cake production reduced by 96 tons per year for each furnace
- Maintenance frequency, time, and operating costs reduction

CHALLENGE

RUSAL is the world's largest producer of aluminium and alumina. The RUSAL Boksitogorsk refinery uses seven 5m diameter, 100m long rotating kilns to produce 165,000 tonnes of argil (a type of clay) a year from bauxite. Kiln temperatures are critical to process efficiency and the quality of the processed material. They are measured using thermocouples attached to the surface of the furnace. Because the kiln rotates the wired devices were connected directly to a slip ring assembly with cylindrical carbon brushes. Due to bearing lubrication thickening in the high temperature environment, the slip rings were not making contact all the time. This led to off spec argil being produced that needed to be reworked. In addition, the furnace had to be shutdown for three hours twice a month to clean the slip rings, reducing overall production volumes.

SOLUTION

RUSAL Boksitogorsk identified wireless as an alternative to the unreliable split ring connection and applied Emerson's Smart Wireless technology as part of a field trial. During a planned shut down of a kiln Emerson's Rosemount® 648 wireless temperature transmitter was connected to the existing thermocouples. The device was mounted on heat-proof ceramic seal to provide protection from temperatures ranging between 240-280°C (460–540°F). The Rosemount wireless device transmits measurement data to a gateway that is connected to a local network via an Ethernet interface. Authorised personnel are able to view this data via a web interface and can ensure the correct kiln temperatures are maintained.

"The wireless solution has uncovered new opportunities for increasing throughput and reducing costs. We have also been able to significantly reduce our maintenance costs associated with temperature monitoring by excluding the use of slip rings."

Vitaly Nikonov
Head of Metrological Department
RUSAL Boksitogorsk

SMART WIRELESS APPLICATIONS

RESULTS

The installation and configuration of the wireless network was very simple and took just one and a half hours to complete. The wireless solution has improved measurement reliability leading to a reduction in off spec product, a reduction in the time spent on maintenance and an increase in availability. This has resulted in an additional 96 tonnes of throughput per year. This first application, now proven successful, is expected to lead to wireless being implemented on the six remaining rotary kilns in the plant.

"Despite a tough environment of metal constructions and electro-magnetic interference, we concluded that the wireless network was extremely reliable with transmission reliability greater than 99%."

Vitaly Nikonov
Head of Metrological Department
RUSAL Boksitogorsk

Rosemount 648 Wireless Temperature Transmitter connected to the kiln's existing thermocouples on a heat-proof ceramic seal.

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Products Prevent Breakdowns and Lost Production on Rotating Reactor at Coogee Chemicals

BENEFITS

- Smart Wireless transmitters replaced wired instruments on plant's rotating chemical reactor that failed frequently
- Control of the process and product quality are greatly improved
- Productivity has increased substantially

CHALLENGE

Coogee Chemicals in Australia produces a wide range of industrial, agricultural and mineral processing chemicals. Obtaining accurate pressure and temperature data from inside the plant's rotating reactor is very important to maintaining process control, but wired instruments were not dependable in this environment. The failure of seals on the slip-rings connecting wires to the rotating equipment allowed the entry of moisture into the instruments. Unreliable temperature and pressure measurements resulted in poor control of the reactor, which had to be shut down two or three times a week.

SOLUTION

The installation at Coogee Chemicals consists of two wireless instruments mounted on one end of a rotating chemical reactor and transmitting pressure and temperature data continuously to a nearby Smart Wireless Gateway. The data is passed from the gateway via Modbus communications to the programmable logic controller (PLC) controlling the process. More reliable inputs enable the PLC to improve both process control and product quality.

RESULTS

Emerson Process Management's Smart Wireless instruments mounted on a rotating reactor are credited with delivering reliable pressure and temperature measurements to prevent frequent reactor breakdowns and lost production time. Control of the process and product quality are greatly improved as a result, and productivity has increased substantially since the wireless instruments were installed in late 2007.

"The Smart Wireless solution provides a means of obtaining accurate pressure and temperature measurements from the moving vessel without having to connect wires to the measurement devices. Wireless delivers reliability where it wasn't available before."

Noel Shrubsall
Electrical Project Officer

For more information:
www.EmersonProcess.com/SmartWireless

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SMART WIRELESS APPLICATIONS

Emerson's *Wireless*HART™ Transmitters Monitor Biomass Gasification Pre-combustion Chamber at Polish Power Plant

BENEFITS

- Increased protection prevents damage to rotating chamber walls
- Long-term reliable data transmission despite tough working environment
- Wireless under consideration for temperature measurement as part of the control of the burning process

CHALLENGE

Elektrownia Stalowa Wola S.A. (part of Tauron Energy) – power plant, Stalowa Wola, Poland produces power and heat by a new gasification system using forest waste wood (including chips and dust) and other biomass material from agriculture. The organic waste passes through a 9m long by 3.5m diameter rotating pre-combustion chamber where it is heated using natural gas to a temperature between 280-360°C. The pre-combustion chamber is made from a ceramic material which is protected from damage by a layer of insulation. To further safeguard equipment, Elektrownia Stalowa Wola wanted to measure the temperature of the pre-combustion chamber walls so that they could be alerted to any potential problems that could damage the chamber walls. Because the chamber rotates, wired transmitters would have required a slip ring assembly to connect the sensors. However, dirt, carbon dust, and other forms of contamination build up in this area which can lead to flash over (arcing between the rings or to ground) and damage the connections between the lead and the rings.

SOLUTION

Two sensors have been installed within the insulation material to provide the temperature measurements of the chamber walls. These are connected in a *Wireless*HART™ network including two Rosemount® wireless temperature transmitters installed on the rotating chamber delivering measurements every 30 seconds. This Smart Wireless solution provides the operator with the information needed to protect the chamber from overheating.

"With every day usage creating the potential for high contamination, we were concerned about the long-term reliability of a slip ring solution. Wireless was the natural alternative and Emerson's WirelessHART devices also meet the EX requirements."

Miroslaw Lysikowski
Instrumentation & Control Manager
Elektrownia Stalowa Wola S.A.

SMART WIRELESS APPLICATIONS

A further transmitter has been installed nearby and acts as a router, strengthening the self-organizing wireless network by providing an extra route for signals to pass through. Measurement data from the sensors is sent via a wireless gateway to the existing Emerson Ovation® expert control system that controls the biomass gasification process.

RESULTS

The sensors and transmitters were installed by Elektrownia Stalowa Wola during a routine shut-down period, taking just two days to complete. Start-up of the wireless network took only a matter of hours, including installing the Modbus TCP/IP cabling that connects the gateway to the control system. Emerson's AMS® Wireless SNAP-ON™ application validated the wireless network and is now used to manage the network and identify any potential trouble spots.

Elektrownia Stalowa Wola is currently considering increasing the number of measurements on the rotating chamber to increase their knowledge of the process and then using wireless temperature measurement as part of the control of the burning process.

"We are extremely happy with the final solution, which has proved to be very reliable. Looking to the future, we expect to use these new measurements for process monitoring and will also be working with Emerson to further expand the use of wireless technology."

Miroslaw Lysikowski
Instrumentation & Control Manager
Elektrownia Stalowa Wola S.A.

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Technology Validates Crude Oil Temperature Monitoring in Storage Tank Protection Systems at BP Dalmeny Terminal, UK

BENEFITS

- Temperature measurements obtained from remote storage tank roof
- Validation of existing protection system
- £15,000 (23,000 USD) recoil system not required
- Wireless infrastructure enables future expansion

"We have been very impressed with the Smart Wireless technology. This site experiences extreme weather conditions, but this has not affected reliability at all."

Robin Hamill
Electrical Instrumentation Engineer
BP Exploration Operating Company

CHALLENGE

Eight interconnecting storage tanks between 40-50m in diameter are used to regulate the flow of stabilised crude oil between production wells and the tankers or pipeline that will transport it to the refinery.

BP records and monitors the temperature of the crude within the tanks via temperature probes mounted on the side of the tank. However it was not known if there was a temperature gradient across the large tanks. Without this knowledge it was impossible to say if the protection system was adequate. A number of measurements were therefore required to confirm any differences in temperature. This presented a challenge because the tanks needed to remain in use, making installation of temperature probes impossible.

An out of service tank with no existing temperature measurement in place presented the perfect opportunity to install the necessary instrumentation. However, there was no cabling infrastructure in place for this specific tank so if BP had installed wired transmitters they would have also had to install a cable recoil system to cope with the floating roof. This would have cost over £15,000 (23,000 USD).

SOLUTION

Two Rosemount® wireless temperature transmitters were installed, one in the centre and one two thirds across to determine if there was a difference in temperatures throughout the tank. A further transmitter was installed on the main inlet feed. The transmitters are located roughly 300m from a Smart Wireless Gateway positioned on the outside wall of the control room. Using a serial connection, data is fed from the gateway into the existing SCADA system.

SMART WIRELESS APPLICATIONS

Installing the Smart Wireless devices was very easy and it took a day to complete the entire project including configuring the serial link to the SCADA system. Emerson's AMS® suite of predictive maintenance software is used to manage the wireless network. Since the wireless network was installed it has been extremely reliable with no data lost.

RESULTS

Using the data from the Smart Wireless transmitters BP discovered that there was not a significant difference in temperature at different points in the tank. They were therefore able to confirm that their existing method of monitoring temperature in the tanks was both accurate and reliable.

BP continues to measure crude oil temperatures in the tank using the Smart Wireless devices. This wireless infrastructure will enable additional wireless instruments to be added quickly and easily in the future.

"The Smart Wireless infrastructure enables us to expand and add additional devices beyond this application without the need for additional cabling infrastructure and the cost associated with it."

Robin Hamill
Electrical Instrumentation Engineer
BP Exploration Operating Company

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SMART WIRELESS APPLICATIONS

Emerson Smart Wireless Technology Used by BP Cherry Point and Naperville to Improve Process Equipment Monitoring and Availability

BENEFITS

- Emerson's Smart Wireless installation unit monitors bearing and calciner coke temperatures to help prevent fan and conveyor failure
- The 15-transmitter wireless installation in 2006, believed to be the world's first industrial wireless mesh network installation, continues to operate reliably

CHALLENGE

BP Cherry Point is a 225,000 bpd refinery, and is the largest supplier of calcined coke to the aluminum industry. One out of every six aluminum cans is made using BP Cherry Point's calcined coke. Fans can cost up to $100,000 to repair but, more importantly, can be down for up to 10 days with associated production losses. BP Cherry Point wanted a way to monitor bearing and calciner coke temperature.

A second facility, BP Naperville R&D, is a world-class technology center including a modernized tank farm feeding an expanding number of pilot plants that develop processing technology options for BP refining worldwide.

SOLUTION

At Cherry Point, Emerson's Smart Wireless installation on the refinery's calciner unit monitors bearing and calciner coke temperatures to help prevent fan and conveyor failure.

The Naperville wireless network uses Rosemount® wireless transmitters to monitor suction, and discharge pressures, levels, flow, and temperatures. New wireless functions are installed as they become available, and emphasis is on collaboration with Emerson to expand the capabilities as rapidly as possible to cover refinery-wide applications. The real-world environment, in a pilot-scale operation, provides feedback to Emerson and hands-on experience for refinery management. Options for refinery process optimization and sharing of wireless automation technology are thereby shared globally by the Refining Technology team.

"The principal advantage we see around wireless is the ability to accumulate and analyze a much greater array of data than would otherwise be economically possible. Wireless enables us to get more data more efficiently, more economically than we ever have been able to in the past."

Michael Ingraham
Technical Manager, BP Cherry Point Refinery

SMART WIRELESS APPLICATIONS

RESULTS

The 15-transmitter wireless installation in 2006 is believed to be the world's first industrial wireless mesh network installation, and continues to operate reliably while eliminating operator rounds in the field. Cherry Point has expanded wireless use to 35 transmitters including tank farm and utility applications, and installation of a Smart Wireless gateway in the diesel unit to make it ready for wireless motes.

Following the first application of Smart Wireless at BP's Cherry Point refinery, BP installed a 45-transmitter wireless network at the Naperville tank farm. Operational for about one year, this has provided strong operational experience and a platform for testing the technology, leading to significant take-up of wireless at other BP refineries throughout the world.

The wireless devices allow operators to be more efficient, collecting data from one central point as opposed to walking around the tank farm and recording all the values. The other advantage of the wireless devices is that they supply data continuously for recording in BP's historian, allowing them to see what is happening in the tank farm at any time of the day.

"Wireless is an important enabler for 'refinery of the future' technologies."

Mark Howard
Commercial Technology Manager, BP

Smart Wireless transmitter installation at BP tank farm.

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SMART WIRELESS APPLICATIONS

Smart Wireless Solutions Enable Temperature Profiling and Tank Level Measurement Redundancy at PPG

BENEFITS

- Easy, cost-effective installation of self-organizing network
- No maintenance required on the network "It just runs"
- Smart Wireless network coexists with other wireless systems

CHALLENGE

PPG needed a cost-effective and reliable solution to enable them to monitor various areas of a vast 765 acre plant which is dense with pipes, buildings and equipment.

SOLUTION

PPG Industries installed and commissioned Smart Wireless solution at its expansive Chemical Division facility in Lake Charles Louisiana. The production installation follows field trials of Emerson's self-organizing wireless networks conducted by a PPG cross-functional process and corporate IT personnel team. The team verified the reliability and coexistence performance of the network, and also deployed it in the plant.

The plant's Smart Wireless network uses ten wireless Rosemount® transmitters for pipeline and steam header temperature measurement which enables operators to watch for cold spots and adjust steam throughput.

PPG also commissioned eight wireless Rosemount transmitters on the self-organizing mesh for tank level measurements to provide backup of primary radar level measurements, helping ensure level control.

RESULTS

PPG estimates installation costs for wired instruments that include near $20 per foot for wiring and conduit. These wireless measurements have the potential to increase process reliability and provide low-cost redundant measurement. PPG is using wireless to make operational improvements by capturing and using new data, and is also anticipating cost advantages.

"Maintenance on the Emerson network?" questioned Reese Borel, process control specialist at PPG. "I haven't had to do any. It just runs."

"When Emerson first approached me with their industrial wireless solution, they said 'We're plug and play.' I have to admit I laughed; nothing I'd seen so far was that easy. But I'm a believer now. Five minutes after installing it, the wireless network came to life. It's been there ever since."

Tim Gerami
Senior Design Engineer, PPG Industries

For more information:
www.EmersonProcess.com/SmartWireless

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Devices Protect "Hot Tanks" at Hunt Refining by Avoiding Cold Spots and Costly Damage

BENEFITS

- Easy and cost-effective installation of Smart Wireless solution helps to prevent costly damage
- Temperature data is carried to the refinery's control system
- Wired or wireless, the data appears the same

CHALLENGE

At Hunt Refining, operators need to keep asphalt at process temperatures above 212° F in about 10 tanks, to avoid formation of cold spots. When very hot asphalt (at 300° to 400° F) is added to a tank, the hot fluid may "melt through" the currently stored asphalt and reach cold pockets where any moisture present can flash off violently. Such "cold spots" can lead to tank failure, with repairs costing up to $200,000 per tank.

SOLUTION

A decision was made at Hunt to install wireless temperature sensors in these tanks and connect the measurement data into the refinery's distributed control system so cold spots could be avoided, and easily identified if they do occur. Three Rosemount® wireless temperature transmitters were positioned 120 degrees apart around the outer circumference of the tank and one to two feet above the bottom. The Smart Wireless Gateway for these transmitters was located about 400 feet away near the I/O building with a repeater between the tank and gateway to assure reception of all signals transmitted on the self-organizing wireless network. Two-wire Modbus communication carries the temperature data from the Smart Wireless Gateway to the refinery's distributed control system. Emerson's AMS® Suite predictive maintenance software is connected along with the Plant Information (PI) network, so the wireless field devices are added to all wired devices managed by this software. Several hot tanks at the refinery are fitted with wireless temperature transmitters as a cost-effective means of keeping control room operators informed of conditions inside the tanks.

"This wireless technology proved to be so reliable and robust it has already been expanded with temperature monitors on more tanks networked to a second Smart Wireless Gateway. That gateway also receives transmissions from a single wireless temperature transmitter monitoring the water being returned to the Black Warrior River to be certain of compliance with environmental regulations."

Dennis Stone
Hunt Refining Process Control Engineer

SMART WIRELESS APPLICATIONS

RESULTS

Wired or wireless, the data appears the same. The installation was simple, and the transmitters came up immediately and talked with the gateway as soon as power was applied. The gateway was easily connected to the distributed control system via a 2-wire Modbus communication. Now, any computer with access to Hunt's Plant Information network can obtain the information.

Each wireless device on a self-organizing network can act as a router for other nearby devices, passing messages along until they reach their destination. If there is an obstruction, transmissions are simply re-routed along the mesh network until a clear path to the Smart Wireless Gateway is found. Although the transmitters at Hunt Refining are spaced evenly around the tank and not within sight of each other, their transmissions easily "bend" around the tank and then on to the repeater and gateway.

As conditions change or new obstacles are encountered in a plant, such as temporary scaffolding, new equipment, or a parked construction trailer, these wireless networks simply reorganize and find a way. All of this happens automatically, without any involvement by the user, providing redundant communication paths and better reliability than direct, line-of-sight communications between individual devices and their gateway. This self-organizing technology optimizes data reliability while minimizing power consumption. It also reduces the effort and infrastructure necessary to set up a successful wireless network.

Smart Wireless transmitter on tank.

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OIL & GAS

ExxonMobil executes project faster with PlantWeb®

RESULTS

- Completed project 6 weeks sooner than with an alternative solution
- 49% lower cost than direct sensor wiring
- 16 man-days saved each time catalyst regeneration is needed

"This is a very powerful solution for ExxonMobil."

Tun Mra Gyaw, Team Leader, I/E/A Reliability Maintenance, Reliability & Engineering, Altona Refinery, Mobil Oil Australia Pty Ltd

APPLICATION

Depleted catalyst from one of two reformer units at the Altona Refinery near Melbourne, Australia, must be regenerated in one of several platinum reformer reactors before reuse. Monitoring the temperature profile of each rector is critical to the success of the regeneration process.

CUSTOMER

Mobil Oil Australia Pty Ltd needed to automate some of the functions that were still being performed manually on the two existing reformer units in the Altona Refinery.

CHALLENGE

It is very important to maintain a gradual and uniform temperature rise without runaway hot-spots throughout the reactor during regeneration. Temperature profile is measured in each reactor using three multi-point sensor arrays. Previously, an I/E technician had to

OIL & GAS

manually connect more than 100 temperature sensors to chart recorders each time it was necessary to regenerate catalyst -- a time-consuming practice. Personnel safety also drove the need for changing the system, since the reactor temperature points are located in a Gas Group IIC hazardous area.

ExxonMobil officials wanted to reduce the time workers were exposed near the high temperature reactors by permanently integrating the measurement points with the refinery's DCS before the next regeneration run. An internal study found that a conventional temperature multiplexer would take too long to deploy, missing the project deadline. In that case, their commitment to reduce personnel exposure during regeneration activities for 2007 could not have been achieved. Furthermore, a temperature multiplexer would have had surge challenges because of the location of several temperature points. A temperature multiplexer would also constitute an unwanted single point of failure.

Other solutions studied included running thermocouple compensation wire back to temperature input cards in the DCS or equipment health monitoring system, but this would have been prohibitively expensive. The most promising solution appeared to be based on the FOUNDATION™ fieldbus technology, because it was both cost-effective and could be completed on schedule.

SOLUTION

Emerson Process Management was selected to provide a PlantWeb® solution consisting of two Rosemount® 3420 Fieldbus Interface Modules with four fieldbus ports each acting as a gateway to ExxonMobil's existing DCS used for operator display and historical trending. Thirty-one Rosemount 848T eight-channel temperature transmitters were mounted near the sensors in junction boxes with each fieldbus segment connecting four transmitters. The eight-channel temperature transmitter is only possible with fieldbus. Emerson provided a complete solution with control panel, FISCO power supply to meet the hazardous area requirements, field junction boxes, etc. The whole solution was pre-engineered and tested by Emerson before shipment to the refinery, drastically reducing the on-site work.

"The new system engineered, supplied, and delivered by Emerson Process Management is a great win for ExxonMobil."

Nick Burchell, Operations Coordinator Refining & Supply, Altona Refinery, Mobil Oil Australia Pty Ltd

As per best practice, the system was designed to avoid any single point of failure. Temperature points are interlaced and distributed across several transmitters in such a way that a single fault cannot cause all measurement points on a reactor to be lost. At least a partial reactor temperature profile will continue to be available. This would not be easy using temperature multiplexers.

The AMS® Suite: Intelligent Device Manager predictive maintenance software taps into the FOUNDATION Fieldbus High Speed Ethernet (HSE), giving plant personnel access to field-generated diagnostics. Burnout of any of the more than 220 thermocouples and problems with the transmitters

OIL & GAS

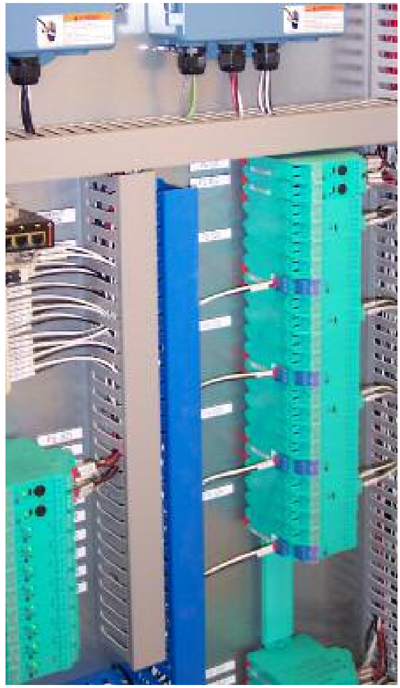
themselves are easily identified in this way so repairs can be made before the next regeneration period.

The project was completed in just eight weeks on a very tight schedule and just in time for the next regeneration. That project was six weeks faster than would have been possible with a multiplexer solution because PlantWeb requires fewer drawings and shorter sensor wire runs.

Considering material, labor, and documentation, the cost of the eight-channel fieldbus transmitter solution was 66 percent lower than with single-input 4-20 mA transmitters, and 49 percent less expensive than direct sensor wiring.

Measurements are now permanently available, and the process unit is ready to regenerate any time without advance notice. As a result, 16 man-days are saved with each regeneration procedure, reducing the overall cost of this operation. This also frees up operators for other tasks. Fewer persons are moving about the plant, meaning improved safety, particularly during regeneration periods.

The temperature profile is now more accurate and displayed on the DCS console, so operators can immediately see a temperature profile change. A gradual and uniform temperature increase is easier to achieve. Operators also have better knowledge of when a regeneration process is complete, so they can stop it before it runs too long. The results are more repeatable, and new operators will find it easier to learn how to operate the reactors.



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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Network Delivers Maintenance Savings, Prevents Unscheduled Shut Downs at Heavy Plate Steel Mill

BENEFITS

- Smart Wireless solution works reliably to protect assets despite harsh plant conditions
- More accurate and redundant data allows Usiminas to better maintain the roll bearings and avoid unscheduled shut downs

CHALLENGE

Usiminas (Usinas Siderúrgicas de Minas Gerais S.A.) in Brazil, one of the world's top steel producers, needed a solution to protect valuable plant assets and avoid unscheduled stoppages at its heavy plate mill in Ipatinga, Brazil. When roll bearings are damaged, it takes at least six hours to shut down the steel plate-making process and replace the set of backup rolls. Usiminas pays from $40,000 to $175,000 to repair each bearing. The company can also lose a minimum of 600 metric tons in production during such an event.

SOLUTION

Eight Rosemount® wireless temperature transmitters installed on the "backup" rolls that are part of the facility's process to produce steel plates measure the temperature of the roll bearing oil. A Smart Wireless gateway collects this critical information and transmits it to the company's distributed control system (DCS). Operators use this wireless data, along with the rolls' return oil temperatures collected by a hard wired network, to automatically monitor the state of bearing health and to keep the steel plate-making process running smoothly.

RESULTS

The self-organizing wireless network consistently provides Usiminas with data even though the temperature transmitters are subjected to extreme heat, water, oil and grease. Installation and commissioning of the new technology was quick and easy.

Usiminas spent four hours commissioning the wireless devices. It would have taken two or three days to commission wired instruments. Usiminas plans to use temperature, pressure and vibration monitors at measurement points throughout the plant, and wireless pH transmitters to monitor wastewater effluent in each area where it's generated.

"The self-organizing wireless network consistently provides Usiminas with data even though the temperature transmitters are subjected to extreme heat, water, oil and grease. Installation and commissioning of the new technology was quick and easy. Usiminas spent four hours commissioning the wireless devices. It would have taken two or three days to commission wired instruments. Usiminas plans to use temperature, pressure and vibration monitors at measurement points throughout the plant, and wireless pH transmitters to monitor wastewater effluent in each area where it's generated."

Carlos Augusto Souza de Oliveira
Usiminas Instrumentation Supervisor

For more information:
www.EmersonProcess.com/SmartWireless

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Solution for Plant-wide Wireless Network Improves Operator Efficiency and Plant Flexibility for Biotech Production Center

BENEFITS

- Increased plant flexibility has helped to diversify production
- Improved operator efficiency
- Plant maintenance efficiency improvements
- Operator station requirements reduced by 50%

CHALLENGE

Novartis, one of the largest and most widely respected pharmaceutical companies in the world, employs over 300 people at Huningue where they produce the active ingredient for Xolair®, a drug used to treat moderate to severe persistent asthma, as well as several monoclonal antibodies and an immunosuppressant. Xolair is derived from genetically modified mammalian cells that are cultivated in a laboratory before being fermented in various bioreactors. Localized control is essential to the efficient management of the process, which is spread over three production levels, as well as being geographically dispersed. A distributed architecture based on Emerson's DeltaV™ digital automation system enabled operator stations to be located near the main areas of the process such as the bioreactors and tanks. To maximize operator efficiency, Novartis recognized that they needed a control architecture that enabled their operators to be fully mobile.

SOLUTION

A plant-wide wireless network was installed to provide a complete mobile wireless solution. Emerson's DeltaV system with a fully integrated Wi-Fi® network and 17 mobile operator stations are providing process and plant information to operators and maintenance staff throughout the facility. Wireless coverage is obtained on all three production levels using 10 Wi-Fi access points spread over two systems. The first system controls the upstream process of cell cultivation and harvesting. The second controls the downstream phase of purification and freezing.

"In 2000 we introduced wireless technology and recognized that it was well suited to our needs. The most recent developments to Emerson's DeltaV system have enabled us to implement a plant wide wireless solution."

Philippe Heitz
Head of Engineering
Novartis

SMART WIRELESS APPLICATIONS

RESULTS

The mobile operator stations provide Novartis with complete flexibility to control its manufacturing processes. Operators can move from one level to another with their mobile station and still maintain an overview of the process. This has significantly improved operator efficiency and made it possible to reduce the number of workstations by 50%.

There have also been efficiency improvements in the area of plant maintenance. For example, by using a mobile workstation it is now possible for just one person to calibrate the instruments when previously it would have required two. Should any workstation have a fault there is no longer a need to shut down a process whilst the station is fixed or replaced. The flexibility offered by the wireless network and mobile workstations provides a perfect back up system.

When a new product is being launched or a recipe changed, the mobile stations can be moved throughout the plant as required, removing the need to install new operator stations. This has helped Novartis to diversify production, changing from a single-chain product, such as Xolair, to being able to produce multi-chain products such as monoclonal antibodies and immunosuppressives.

"Because of the wireless network, we do not need to systematically invest in new control stations, even if the production of new products requires a change to the plant equipment or layout."

Philippe Heitz
Head of Engineering
Novartis

Mobile operator stations provide Novartis with complete flexibility to control its manufacturing process.

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Network Improves Carbon Reactivation Process at Calgon Carbon

BENEFITS

- Wireless temperature transmitters attached to a rotating kiln deliver continuous information for instant response to process changes, enabling better heat control
- Smart Wireless network was easily installed at a reduced cost over a wired solution
- Temperature measurements are integrated in a host PLC

CHALLENGE

As the world's largest manufacturer and supplier of granular activated carbon, Calgon Carbon operates several reactivation plants to prepare carbon for reuse by removing chemicals picked up in previous filtering of air, gases, water, and other liquids. They were looking for a way to make process improvements through providing continuous temperature measurements from a rotating catalyst kiln where spent carbon particles are reactivated. The reactivation process involves passing recycled carbon through the kiln where it is dried and chemicals it has absorbed are "cooked off" at temperatures ranging between 1400°F and 1800°F. Measuring the temperature at each zone in the kiln is important to ensure proper heat transfer for each step in the process.

SOLUTION

Six Rosemount® wireless temperature transmitters were installed to monitor temperatures in the kiln and transmit a steady stream of data, giving operators more information for controlling heat levels in each zone. The wireless transmitters mounted on raised platforms on the surface of the kiln were simply connected to the existing thermocouples, and the *Wireless*HART self-organizing mesh network was set up with a single Smart Wireless gateway. The six transmitters monitor temperatures in five zones of the kiln and at the outlet, communicating data reliably from the rotating kiln to the gateway, which then integrates the measurements in a host PLC.

"We used WirelessHART because of the ease of installing the network, the reduced cost of installation, and the ability to communicate in spite of the constant rotation of the kiln. Non-wireless methods were too expensive, and other wireless line-of-sight systems could not handle the kiln's movement."

Jeremy Dolan
Site Manager, Calgon Carbon

SMART WIRELESS APPLICATIONS

RESULTS

Smart Wireless was chosen because of the ease of installing the network, the reduced cost of installation, and the ability to communicate in spite of the constant rotation of the kiln. Non-wireless methods were too expensive, and other wireless line-of-sight systems could not handle the kiln's movement. The effects of process changes on heat transfer are now readily apparent, and trending can be used to improve process efficiency. This was not possible previously with the limited amount of information generated every two hours through manual viewing of readouts on devices connected to thermocouples in the kiln. By contrast, other carbon reactivation plants employ a conduit through the center of the kiln with thermocouple "spiders" going out into each zone. This method "very expensive to install and difficult to maintain."

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SMART WIRELESS APPLICATIONS

Emerson's Smart Wireless Helps San Diego Gas & Electric Improve Operations and Safety as Well as Extend Asset Life

BENEFITS

- Integrates with the plant's Ovation® expert control system providing additional insight to field information
- Protects against pump damage valued at $20,000 per pump
- Lengthens motor life, saving $15,000-$20,000 per motor every 5 years
- Eliminated wire and cable costs, saving $5,000-$8,000 per device
- Installed each device in 1 hour versus an estimated 2 weeks to run cable for a single wired monitor

CHALLENGE

San Diego Gas and Electric (SDG&E) is a regulated public utility that provides energy service to 3.4 million consumers throughout San Diego and South Orange County.

SDG&E wanted to implement a wireless architecture throughout the Palomar combined cycle plant in order to access data that was previously unattainable through traditional wired solutions. The wireless data would be used in various efficiency calculations at the plant. Project goals included:

- Straightforward project implementation by plant personnel
- Achieve cost savings versus traditional wired applications
- Improve Operational efficiencies
- Enhance plant safety and asset protection

SOLUTION

Five applications of Emerson's *Wireless*HART™ network at the Palomar Energy Center use Rosemount® wireless transmitters communicating with a single Smart Wireless Gateway to collect new, continuous data for SDG&E.

The wireless network is integrated into Emerson's Ovation expert control system, providing access to additional plant and process data for control and asset optimization, which translates into operational efficiencies and performance improvements.

"Emerson Smart Wireless is very easy, very reliable. We used wireless for the ease of installation; we did not have to run any power or instrument wiring resulting in cost savings. Another great benefit was the fact that we could install the devices ourselves instead of hiring contractors. The ability to do it ourselves in a fraction of the time delivered big savings."

Steve Lyons
Instrument Technician
San Diego Gas & Electric, Palomar Energy Center

SMART WIRELESS APPLICATIONS

RESULTS

SDG&E has increased its cooling water throughput with the help of real-time cooling riser data delivered by Rosemount wireless temperature transmitters. This data is used in efficiency calculations to verify that cooling fans are running at correct speeds. Confirmation of properly operating cooling fans eliminates the need to over-compensate, which gives the plant better thermal efficiency.

In a second application, turbine compartment temperatures are checked continuously by wireless temperature transmitters to detect cooling air leaks. The new data has allowed SDG&E to cut preventative maintenance on the turbines in half.

A third Smart Wireless application of Rosemount wireless pressure transmitters detect air leaks from two forced draft fans as each alternately sit idle while the other runs to cool turbines. Wireless pressure data helped find leaks in a more expeditious manner. SDG&E is now able to lower the fans' amps, which has lengthened their lifetime, saving at least one fan motor every five years, providing an estimated savings of $15,000 to $20,000.

In a fourth application, Rosemount wireless DP transmitters check inlet air filters that protect turbine blades in an area subjected to construction dust which severely reduces efficiency. After installing wireless DP, turbine efficiency has improved and megawatt usage was reduced. Better DP information across the filters enables plant personnel to clean them at the proper time.

In a fifth Smart Wireless application,a Rosemount wireless temperature transmitter monitors pipes on the facility's fire safety system. Pipe temperatures can rise to 160°F if pumps are accidently left on after weekly tests. Use of wireless helps to protect against pump damage, which could cost the plant $20,000 per pump, and protect plant personnel from burns.

Because wireless is flexible and scalable, power producers can adopt this approach wherever it makes sense for their plant. By picking even one small application, users can achieve improvements that would not be possible in a traditional plant configuration.

"The new data provided by the Smart Wireless network allows us to perform maintenance when needed, and less on a scheduled basis. As a result, we have cut our preventive maintenance on the turbines in half. Additionally, after installing wireless DP transmitters, we have improved turbine efficiency and reduced our megawatt usage."

Steve Lyons
Instrument Technician
San Diego Gas & Electric, Palomar Energy Center

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EMERSON
Process Management

ONSHORE PRODUCTION — SMART WIRELESS

Oil Producer Reduces Production Loss with Smart Wireless Technology

RESULTS

- Reduced production loss through increased visibility of well production
- Reduced operations and maintenance costs
- Decreased health, safety, and environmental risks

Smart Wireless allowed this customer to be more proactive in production management and decrease production loss.

APPLICATION

Gross oil production flow monitoring

CUSTOMER

Independent oil and gas producer

CHALLENGE

Being able to measure the gross oil production at a site is extremely important to understanding the performance of a given well. This customer used portable meter skids to measure well performance on a monthly or semi-annual basis. When the skid was not onsite, the last tested measurement was assumed until the portable meter skid returned to the site. Because the flow measurement was assumed, the company was guessing that the well was performing at the same level during the duration the skid was not on location.

Other than the routine portable skid measurement, no measurement was made at these sites because of the costs associated with installing measurement points. Labor and infrastructure costs including RTU's, cabling, batteries, and radios made it cost prohibitive to replace the portable skids system.

By not having measurement on the well site, this company could not quickly identify where production problems were arising. This resulted in reactive operations, lower well production, and increased safety risks.

SOLUTION

The customer installed a Smart Wireless self-organizing network from Emerson Process Management. The Rosemount 3051S Wireless Pressure Transmitter and Rosemount 648 Wireless Temperature Transmitter were installed for gross oil monitoring. Smart Wireless allowed the client to keep track of individual well production at all times.

The self-organizing network provided greater than 99% data reliability so that well problems could be identified near real-time. Extended range communication of up to a half mile provided a stronger network with many devices communicating into a gateway from multiple wells.

The Rosemount 3051S Wireless Pressure Transmitter Installed

ONSHORE PRODUCTION

Communication reliability is only as strong as the reliability of the devices and the quality of data they provide. The Rosemount 3051S Wireless Pressure Transmitter and Rosemount 648 Wireless Temperature Transmitter lead the industry in both reliability and performance, making them ideal for this remote oilfield application.

By using the Smart Wireless solution, gross production levels could now be monitored near real-time for well production management to prevent production loss. Skid rental costs were eliminated, as were the safety and environmental risks associated with skid relocation such as driving, spills, lifting, and working with high pressure lines.

Capital costs to install the Smart Wireless network were also much less than if the customer chose the traditional architecture with RTUs, batteries, and radios. For this application, a Smart Wireless architecture eliminated all the infrastructure and wiring normally associated with oilfield automation.

RESOURCES

Emerson Smart Wireless

http://www.emersonprocess.com/rosemount/smartwireless/index.html

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00830-0100-4802, Rev AA

10

Glossary

A

Absolute Zero
Lowest possible point on the scale of absolute temperature. The point at which molecular activity ceases and thermal energy is at a minimum. Defined as -272.3 °C; -489.7 °F; or 0 °K

Acceptance Testing
The acceptance testing procedure is similar to the commissioning procedure but is intended for an official turn-over of a system that is operating according to design specification from the vendor to the owner. For some systems, especially for SIS, this is first conducted at the vendor facility, known as Factory Acceptance Testing or FAT, and then again after installation and commissioning. The terms Site Acceptance Testing (SAT) and Pre-start-up Acceptance Testing (PSAT) are often applied. (See Section 4.2.5.2.6)

Accuracy
Accuracy of a measurement system is the degree of closeness of measurements of a quantity to that quantity's actual (true) value.

Accuracy Ratio
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. (See Section 5.7.3)

Alarm
Alarms cover diagnostics that are determined to affect the transmitter's ability to output a correct value of the measurement. In a transmitter the output signal will drive to a predetermined value.

Alert
Alerts cover diagnostics that are determined not to affect the transmitter's ability to output the correct measurement signal and therefore will not interrupt the 4-20 mA output.

Alpha value
RTD elements are characterized by their Temperature Coefficient of Resistance (TCR) also referred to as its alpha value. The alpha value is the temperature coefficient for that specific material and composition. (See 3.2.3.6.1)

Alumel®
An alloy consisting of approximately 95% nickel, 2% manganese, 2% aluminum and 1% silicon. This magnetic alloy is used for making Type K thermocouples and thermocouple extension wire. Alumel is a registered trademark of Hoskins Manufacturing Company.

Ambient temperature compensation
Both input and output accuracy will vary with fluctuations in the ambient temperature of the transmitter. Transmitters are characterized during manufacturing over their specified operating range to compensate for these fluctuations to maintain measurement accuracy and stability. (See 3.1.4.1.5)

Analog output
Industry standard 4-20 mA analog signals are used globally to communicate from field mounted devices over long distances to control systems, data loggers and recorders.

Analog-to-digital (A/D)
Conversion of an analog signal to a digital signal.

Analog-to-digital converter (ADC)
In a temperature transmitter the input subsystem converts the sensor measurement signal into a digital signal for further processing within the transmitter.

ASTM E1137
American Society for Testing and Materials standard applies to platinum RTDs with an average temperature coefficient of resistance of 0.385 %/ °C between 0 and 100 °C and nominal resistance at 0 °C of 100 Ω or other specified value. This specification covers platinum RTDs suitable for all or part of the temperature range between -200 to 650 °C. (See 3.2.11)

B

Barstock thermowells
Are machined from a solid piece of round or hex shaped metal and can withstand higher pressures and faster flow rates than protection tubes. They have more material options and can be mounted in various ways to meet different process pressure requirements.

BPCS
Basic Process Control System aka a DCS or PLC

Bayonet spring loaded
a bayonet spring loaded style of sensor that is similar to spring loaded style but allows removal of the capsule without disassembly of the threaded adapter from the thermowell.

C

Calendar-Van Dusen Equation (CVD)
This equation describes the relationship between resistance and temperature of platinum resistance thermometers (RTDs). For the sensor – transmitter matching process the user enters the four sensor specific Callendar-Van-Dusen constants into the transmitter. The transmitter uses these sensor-specific constants in solving the CVD equation to match the transmitter to that specific sensor thus providing outstanding accuracy. (See 3.2.3.12)

Calibration
A comparison of measuring instrument against a standard instrument of higher accuracy to detect, correlate, adjust, rectify and document the accuracy of the instrument being compared. (See 5.7)

Calibrator
Any of a variety of devices that can generate a known signal to be applied to an instrument to be calibrated and can read the response of that instrument for verification and/or adjustment. There are bench models and battery powered field models. Some have a wide variety of signal generation capability and some models have fieldbus interface capability.

Capsule style
A sensor sheath with lead wires. Capsules are commonly used with compression fittings and can be cost-effective mounting method when environmental conditions are not a concern.

CCST
Certified Control System Technician accreditation from ISA or other training program.

Certifications
Instruments typically offer a variety of certifications that include manufacturing locations, EU directives, hazardous locations, and safety.

Chromel®
An alloy made of approximately 90 percent nickel and 10 percent chromium that is used to make the positive conductors of ANSI Type E (chromel-constantan) and K (chromel-alumel) thermocouples. It can be used up to 1100 °C in oxidizing atmospheres. Chromel is a registered trademark of the Hoskins Manufacturing Company.

Coiled sensors (also called Coil Suspension)
A style of RTD sensor that is designed for rugged applications that also require high accuracy and fast response. The element is constructed with a high purity platinum wire that is wound in a helical coil to minimize stress and assure accurate readings over long periods of time. Each coil is fully suspended in a high purity ceramic insulator and surrounded by a ceramic powder with a binder additive. (See3.2.3.2.2)

Cold junction
Known as the reference junction, is the termination point outside of the process where the temperature is known and where the voltage is being measured. (Typically in a transmitter or signal conditioner.)

Cold junction compensation (CJC)
The voltage measured at the cold junction correlates to the temperature difference between the hot and cold junctions; therefore, the temperature at the cold junction must be known for the hot junction temperature to be calculated. This process is known as "cold junction compensation" (CJC). CJC is performed by the temperature transmitter, T/C input cards for a DCS or PLC, alarm trips, or other signal conditioner. Ideally the CJC measurement is performed as close to the measurement point as possible because long T/C wires are susceptible to electrical noise and signal degradation. Also described as the adjustment made by a temperature transmitter to improve accuracy by factoring in the actual cold junction temperature of a thermocouple. The CJC depends on a reference temperature device built into the transmitter. (See 3.2.4.2)

Commissioning
Includes verifying every connection of every loop is properly secured, tagged and connected at both the field and control room ends. It further includes an operational check of each loop to verify that all settings are properly set and that the functionality of the design has been implemented. Extensive use of loop sheets and instrument specification sheets helps to guide this procedure.

Compensating Leads
In some cases where economic considerations may preclude the high cost of exotic metal extension wires as are used in Types R, S, and B thermocouples a less expensive alloy that has similar emf may be used. Performance will be compromised to a degree.

Convection
The transfer of heat from one place to another by the movement of fluids. Convection is usually the dominant form of heat transfer in liquids and gases. This effect is evidenced in heat transfer from a process to a sensor for temperature measurement.

Copper RTD
Commonly used in winding temperature measurements of motors, generators and turbines. 10 Ω copper RTDs have been most common over the years but are now giving way to 100 Ω and even 1000 Ω models to get better resolution of the measurement. Note that Platinum RTDs are also growing in popularity for these applications.

Conduction error
The transfer of heat energy where heat spontaneously flows from a body at a higher temperature to a body at a lower temperature. In the case of a temperature sensor this conductive heat loss tends to change the actual temperature being measured thus causing a measurement error.

Conduit Seal
Any of a variety of methods to seal the wiring openings on an instrument or field junction box housing to prevent egress of water, moisture, or other contaminants.

Configuration
The process of configuration includes the selection and adjustment of a wide assortment of transmitter operating parameters including the most simplistic to the more advanced features.

Cost of ownership
A purchase validation technique that considers not only purchase price but also the costs assocated with installation, operation, maintenance and return on investment (ROI).

Cryogenic
Means “producing, or related to, low temperatures,” and all cryogenic liquids are extremely cold. Cryogenic liquids have boiling points below -150 °C (- 238 °F)

D

Damping
A transmitter function that reduces temperature fluctuations by slowing and smoothing the output, resulting in a more stable temperature readings. (See section 3.1.6.1)

DCS
Distributed Control System a.k.a. Basic Process Control System (BPCS)

DIN
Acronym for Deutsche Industrie Normenausschuss which is a German agency that sets engineering and dimensional standards that are globally recognized

DIN Style Sensor
A sensor capsule with a circular plate that provides a connection to the connection head or housing. The benefit of the DIN style is the ability to install and replace the sensors without removing the connection head or housing as it is inserted through the housing instead of threaded into the bottom. All DIN styles are spring loaded.

Direct Mounting
Attachment of a transmitter directly to a sensor or well assembly. Also called integral mounting. (See 3.1.10)

Drift
In temperature measurement it is the movement of the measured value away from the actual value. There is a very small drift in a transmitter and there is a small and predictable drift with an RTD when operated at temperatures below 300ºC and there is a more significant and unpredictable or erratic drift with a thermocouple that is related to junction degradation. Higher temperature operation greatly exacerbates sensor drift error. (See 3.2.3.13)

Dry Block
Also called a temperature calibration block – consists of a heatable and/or coolable metallic block, controller, an internal control sensor and optional readout for an external reference sensor. It is used to compare a temperature sensor against a known temperature as part of the calibration process. (See 5.75 and 5.75.1)

Dual Compartment
A two part housing, often known as field mount, that isolates the transmitter electronics module from the terminal strip compartment to protect it from exposure to harsh plant environments. The terminal compartment contains the terminal and test connections for the sensor and signal wires and provides access to the terminal block for wiring and maintenance while isolating the transmitter electronics which are in the second compartment. (See 3.1.10.2)

Dual element
Type of RTD or T/C sensor with two independent sensing elements within the sensor sheath. With RTDs they are always isolated from each other. Isolated configurations exist when two independent T/C junctions are placed inside one sheath. Un-isolated configurations exist when two T/C junctions are placed inside one sheath where all four T/C wires are mechanically joined.(See 3.2.3.1.1 and 3.2.4.3.2)

E

EMC
Electromagnetic compatibility. Compliance with national or international standards is often required by laws passed by individual nations. (See 3.1.7)

EMF
Electromotive Force. An electrical potential energy measured in volts. It is the term given to the millivolt signal produced by a thermocouple sensing element.

EMI
Electromagnetic Interference, caused by large motors, motor starters, welders, contactors and other electrical equipment that dramatically effects electronic devices. Quality devices will incorporate filtering algorithms to eliminate the influence of this interference.

Endothermic
A process that absorbs heat.

Errors
The deviation of a value from its true value. There will always be some error in a temperature measurement system. Proper choice of components, installation and operation will tend to minimize the error value.

ESD
Electrostatic Discharge, characterized by a sudden flow of electricity most often associated with lightning and other arcing sources.

Exposed junction
Associated with T/Cs that have the hot junction extending past the sealed end of the sheath to provide faster response. The seal prevents intrusion of moisture or contaminants. These are typically applied only with non-corrosive gases as might be found in an air duct.

Exothermic
A process that gives off or produces heat.

Extensions
Sensor assemblies can include extensions of various lengths to accommodate for different insulation thicknesses and high process temperatures that may affect the transmitter electronics. Extensions can be a combination of unions, nipples, and/or couplings.

External diagnostics
Monitor measurement validity due to external sources, such as the sensor wiring connections, noise on the sensor, and sensor failure. (See 3.1.8)

F

Four-wire RTD
It uses a measurement technique where a very small constant current is applied to the sensor through two leads and the voltage developed across the sensor is measured over the other two wires with a high-impedance and high resolution measuring circuit. (See 3.2.3.1.3.1)

FOUNDATION™ Fieldbus
an all-digital, serial, two-way communications system that can serve as the base-level network in a plant or factory automation environment. It is an open architecture, developed and administered by the Fieldbus Foundation.(See 3.1.3.3)

Frictional Heating
Heating effects upon a sensor that is immersed in a high viscosity fluid moving at high flow rates. The heating effects are proportional to the square of the fluid velocity.

G

Ground / Grounding
A reference point in an electrical circuit that is physically connected to an earth ground point. For instrumentation applications this connection must have a very low resistance path to earth to ensure proper operation of electronic devices and should never be connected to the same location as power ground. Multiple ground points in any circuit can cause disruptive ground loops. (See 4.2.5.2.4.1)

Grounded T/C junctions
Created when the thermocouple junction is connected to the sensor sheath which is in turn connected to the process vessels or piping which is assumed at a ground potential.

H

HART®
The HART (Highway Addressable Remote Transducer) protocol is a digital protocol that provides for the superimposing of a digital signal onto the 4-20 mA signal wires. This superimposed digital signal allows two way communications for configuration and for extracting operational and alarm data from the transmitter. (See 3.1.3.2)

Head mount transmitter
Head-mount transmitters are compact disc shaped transmitters most often mounted within a connection head. The most common types are referred to as DIN A and DIN B which are differentiated by mounting style and dimensions. (See 3.1.10.1)

Heat Transfer
The process of thermal energy flowing from a body of high energy to a body of low energy. Energy transfer is by conduction, convection and radiation. The process is the very basics of temperature measurement.

Hermetic Seal
A protective method to prevent the intrusion of air, gas or liquid into a device. Most temperature sensors have a hermetic seal where the leads protrude from the sheath to preserve the integrity of the sensing element.

Hot junction
The hot junction measuring element of a thermocouple is placed inside a sensor sheath and exposed to the process. (See 3.2.4.1)

Hysteresis
Is a phenomenon that results in a difference in an item's behavior when approached from a different direction. In laboratory grade RTDs there is negligible hysteresis while an industrial grade sensor with its inherent rugged design does have a small hysteresis error. (See 3.2.3.9)

I

Ice Point
The temperature, equal to 0 °C (32 °F), at which pure water and ice are in equilibrium in a mixture at 1 atmosphere of pressure.

IEC 60751
The most commonly used standard for Platinum RTDs defines two performance classes for 100Ω, 0.00385 alpha Pt RTDs, Class A and Class B. These performance classes (also known as DIN A and DIN B due to DIN 43760) define tolerances on ice point and temperature accuracy. These tolerances are also often applied to Pt RTDs (See 3.2.3.10)

IEC 61511
A performance based safety standard endorsed by OSHA and ISA. It includes a safety lifecycle that provides user guidance for systems from conception to de-commissioning. (See section 8.3)

Immersion
The condition where temperature sensors are inserted into the process medium; furthermore, they are typically installed into a thermowell for protection against process conditions. As contrasted to surface mounted sensors.

Input Accuracy
Also called digital accuracy, is unique for each type of sensor input. For example, the input accuracy of an RTD is about +/- 0.1 °C (0.18 °F) for a high quality transmitter. The input accuracy of a T/C

varies by T/C type from about +/-0.2 °C (0.36 °F) up to +/-0.8 °C (1.44 °F). There are many factors that affect the accuracy of a transmitter, including ambient temperature compensation, CJC and sensor selection. (See 3.1.4.1.3)

Instrument Error
The difference between the actual value of a measurement and the value being presented by the instrument. The error has components related to the design of the instrument as well as external factors such as ambient temperature variation, lead wire issues, and electrical and electronic noise.

Insulation Resistance
The resistance measured between the sensing element and the protective sheath. As a sensor ages and the insulation begins to deteriorate or absorb moisture from leaks in the sensor hermetic seal, the performance of the sensor deteriorates.

Integral mount
Where the transmitter is mounted directly to a thermowell. As contrasted to remote mounting. (See 3.1.10.1)

International Standards
Several international standards define the relationship between resistance and temperature for RTD sensors. The two that are most common are ASTM 1137 (American) and IEC 60751 (European). For T/Cs ASTM E230 -11 and IEC 60584-2 are predominant. (See 3.2.3.14 and 3.2.4.5)

Input
The low-level signal from a temperature sensing element to a transmitter or an input card. It can be resistance from an RTD or a millivoltage from a T/C.

Input Card
A generic name given to any of a variety of input modules typically associated with the I/O subsystem of a distributed control system (DCS). Different versions accept low level sensor signals, 4-20 mA current signals, and frequency signals. It may be located in a junction box in the field or near the control room.

Immersion Length
The length from the tip end to the mounting shoulder of an RTD either for immersion directly into a process fluid or insertion into a thermowell.

Insertion length
The portion of a thermowell exposed in a process fluid measured from the face of the flange surface or the base of the weld to the tip of the well. (See 4.2.2.2.5)

Installation Detail Drawing
Tells contractors and pipefitters the location of each measurement point and how the components are to be installed. This construction document evolves from many decisions regarding thermowells, sensor elements, connection heads, transmitters, etc. (See 4.2.6.4)

Instrument Lists
Document every instrument comprising the input/output loops, and there can be hundreds of such loops in one automated process. Columns show the type of sensor its model number and manufacturer, the service, the transmitter type model number and manufacturer, the tag name/number for each device, and the location on the P&ID. (See 4.2.6.6)

Insulation Error
Temperature measurement error caused by an electrical shunt or degraded insulation between a sensor element and its sheath.

Insulation Resistance
The resistance of the insulating material used to fill in the sheath around the sensor element. It is typically Aluminum oxide or magnesium oxide.

Intelligent devices
Another term for Smart devices that are microprocessor-based and capable of extraordinary capabilities to process a measurement signal, apply intelligent filtering, apply a wide array of diagnostic functions and condition it for transmission via either an analog or digital signal.

Interchangeability
All sensors have inherent inaccuracies or offsets from an ideal theoretical performance curve referred to as sensor interchangeability. IEC standard 751 sets two tolerance classes for the interchangeability of platinum RTDs: Class A and Class B. (See 3.2.11)

Interchangeability Error of a Sensor
Defined as the difference between the actual RTD curve and the ideal RTD curve. The IEC 60751 standard uses only the ice point resistance R0 and the sensor Alpha Number to define an approximation of an ideal curve.

Internal lead wires
Very fine wires are used inside the sheath to connect to the sensing element and then are welded to heavier lead wires at the end of the sheath that are used to connect to a terminal block, transmitter or other termination point.

Isolation
Most transmitter designs incorporate a means of galvanic isolation using either optic or transformer isolation stages to eliminate ground loop problems and to block both normal mode and common mode voltages that may inadvertently come in contact with the measurement circuit. (See 3.1.2.2)

Isothermal
Of or relating to constant temperature and is usually applied to the terminal area of a thermocouple transmitter where the cold junction temperature is measured.

J

JJG 229
A Chinese standard is also known as “Regulations of Industry Platinum and Copper Resistance Thermometers”.

Junction Types
T/C Junctions are manufactured in different configurations each with benefits for specific applica-tions. Junctions can be grounded or ungrounded, and dual element thermocouples can be isolated or non-isolated.

Grounded T/C junctions are formed when the thermocouple junction is connected to the sensor sheath. (See 3.2.4.3)

Ungrounded junctions exist when the T/C elements are not connected to the sensor sheath but are surrounded with insulating MgO powder.

Exposed junction T/Cs have the hot junction extending past the sealed end of the sheath to provide faster response.

L

LCD Display
An option on a temperature transmitter that displays the measured temperature, range, engineering units, device status, error messages and diagnostic messages. (See 3.1.11.2.1)

Lead Wires
The wires protruding from the end of a sensor sheath that are connected to a transmitter or other terminal strip.

Lead Wire Color Coding
The IEC 60751 defines the standard colors for RTD lead wire combinations. ASTM E230 and IEC 60584 are the most commonly used standards for thermocouple lead wire colors. See Table 3.2.4.5a for more detail.

Lead Wire Compensation
RTD - Since the lead wires are part of the RTD circuit, the lead wire resistance needs to be compensated for to achieve the best accuracy. This becomes especially critical in applications where long sensor and/or lead wires are used. (See 3.2.3.1.3.1)

Lead Wire Error
The error created by lead wires is vastly different for 2, 3 and 4 wire RTD circuits. Very large errors are associated with 2-wire circuits with long lead wires. The error is much less with 3-wire circuits and is almost nil with 4-wire circuits. (See 3.2.3.1.3.1)

Line Voltage Filter
Noise from nearby 50 or 60Hz AC voltage sources, such as pumps, variable frequency drives, or power lines is easily detected by low-amplitude sensor signals. If not recognized and removed, this noise can compromise the transmitter’s output signal. A transmitter’s Line Voltage Filter can be customized at 50 or 60 Hz to protect temperature measurements from AC voltage interference and to filter out this noise. (See 3.1.6.5)

Linearization
All T/C’s and RTD’s have a nonlinear output vs. temperature relationship. If this relationship was ignored, significant errors would result, especially for wider ranges. The transmitter applies a linearization technique that greatly reduces the errors caused by the nonlinearities of sensors thus providing a much more accurate measurement. (See 3.1.2.4.2)

Local Operator Interface (LOI)
The LOI interface provides the ability for local configuration of the device to make changes in real time without having to attach a laptop or field communicator. The buttons on the LOI are used to perform the configuration tasks by following a menu of configuration information. (See 3.1.11.2.2)

Logic Solver
The term given to the safety certified controller that implements the required logic in a safety instrumented system (SIS). It may be as simple as a single channel safety-certified alarm trip module or as complex as a quad-redundant PLC system.

Loop Sheets
Are developed in some cases, with detailed wiring schematics for the sensors, junction boxes, transmitters, power supplies, and marshalling points reflecting the system architecture. Every loop is numbered, and every sensor and device in the field is tagged. (See 4.2.6.5)

Loop Test
A term applied to the process of verifying that an instrument loop is properly installed and functional in accordance with operational and functional specifications by applying a simulated signal at the transmitter and verifying the proper response at the receiving device. (See 5.7.4)

M

Management of Change (MOC)
Is the process where any changes are proposed to the Safety Instrumented System, that are not like-in-kind changes. For example using a different model or supplier from that in the original design. The Management of Change procedures for the facility should be followed to completely evaluate and consider the impact of those changes to identify any potential hazards that could result from those changes prior to implementation.

Mandrel
Wire-wound RTDs are manufactured by winding the resistive wire around a ceramic mandrel with a closely matching coefficient of expansion to the wire to minimize element strain effects. (See 3.2.3)

Matching
A precise compensation for RTD inaccuracies is provided by Transmitter-Sensor Matching using the transmitter's factory programmed Callendar–Van Dusen equation. This equation describes the relationship between resistance and temperature of platinum resistance thermometers (RTDs). The matching process allows the user to enter the four sensor specific Callendar-Van-Dusen constants into the transmitter. The transmitter uses these sensor-specific constants in solving the CVD equation to match the transmitter to that specific sensor thus providing outstanding accuracy. (See 3.2.3.12)

Measurement Instruments Directive (MID)
Is a directive by the European Union, which intends to create a common market for measuring instruments across the 27 countries of the EU. Its most prominent tenet is that all kinds of meters which receive a MID approval may be used in all countries across the EU. High-end temperature measurement systems for temperature compensation of custody transfer must be certified for compliance. (See Chapter 6, Best Practices #24)

N

National Metrology Institute
A standard sensor has accuracy traceability to a National Metrology Institute of the user country like NIST in the USA, NPL in the UK, and PTB in Germany among others. These institutes have the highest precision standards against which others are compared for certification. (See 5.7.2)

Nickel RTD
Nickel elements have a limited temperature range because the amount of change in resistance per degree of change in temperature becomes very non-linear at temperatures over 300 °C. Use of nickel RTDs has declined over the years due to its performance limitations and since the cost of Platinum RTDs is now a very small premium, if any at all.

Noise
Virtually every plant environment contains electrical interference sources like pumps, motors, Variable Frequency Drives (VFD's) and radios as well as sources of electrostatic discharge and other electrical transients. These are Electromagnetic Interference (EMI), Electrostatic Discharge (ESD), and Radio Frequency Interference (RFI).

Nuclear Radiation
Radiation effects that can induce measurement error in temperature measurements. Effects include gamma, fast neutron, and thermal neutron radiation.

O

Output Accuracy
Is a statement of the accuracy of the D/A converter stage of a transmitter given as a percentage of span.

P

P&ID
Piping and Instrumentation Diagram. Shows the anticipated need for measurement and control instrumentation. The P&ID does not indicate precisely where to install the sensors and transmitters, leaving a great deal of latitude in the selection and placement of the specific components by the engineering staff and piping designer. (See Figure 4.2.6.3a)

Peltier–Seebeck effect
The Peltier effect, first exhibited by Jean Peltier in 1834, is viewed as the compliment to the Seebeck effect and describes the ability to generate a heat variation due to a voltage difference across a two dissimilar metals at the junction.

Pipe Cleaning Pig
A cylindrical device that fits tightly inside a pipeline and is propelled or towed through the line to clean out deposits and residue.

Platinum wire
Used for the manufacture of platinum RTDs it typically has a purity of about 99.99% so that its temperature response characteristics are very predictable against published resistance vs. temperature curves. (See Alpha curve)

Plot Plan
An engineering plan drawing or diagram which shows the buildings, utility runs, and equipment layout, the position of roads, and other constructions of an existing or proposed project site at a defined scale. Plot plans are also known more commonly as site plans. (See 4.2.6.1)

Potentiometer
A variable resistance device where a pickup or "wiper" slides along the resistance in accordance with some external physical movement thus developing a variable resistance output to the transmitter.

Primary Standard
A standard sensor has accuracy traceability to a National Metrology Institute of the user country like NIST in the USA, NPL in the UK, and PTB in Germany among others. To communicate the quality of a calibration standard the calibration value is often accompanied by a traceable uncertainty statement to a stated confidence level. (See 5.7.2)

Process Connection
Usually refers to the design of the thermowell or sensor that mounts into the process. For bare sensors it is usually threaded and for sensors in a thermowell they are typically threaded, welded or flanged.

Process Flow Diagram
Shows the major pieces of equipment in a process area and the design operating conditions.

PROFIBUS
Is an international communications standard for linking process control and plant automation modules. Instead of running individual cables from a main controller to each sensor and actuator, a single multi-drop cable is used to connect all devices, with high speed, bi-directional, serial messaging used for transfers of information. (See 3.1.3.4)

Protection Tubes
Sometimes called Tubular Thermowells - are fashioned by welding a flange or threaded fitting to one end of tube or small section of pipe or tubing and capping the other end. Protection tubes can also be constructed of ceramic material and bonded to a process fitting. Tubular thermowells can be constructed for very long immersion lengths and are often used for measurements where flow forces are low. (See 3.3.3.2.1)

Proven-in-Use
In a SIL rated safety loop there are occasions when it is thought desirable to use an instrument or a component well known to the user that has not been assessed under the IEC61508 group of standards e.g. by an FMEDA*. The Functional Safety standards allow the use of such equipment only on the basis that it

has been “proven in use” (61508) or has a history of “prior use” (61511). (See 8.3)

It is the end user who must ensure that the Safety Instrumented System (SIS) meets the requirements of the standard. He can do that by assessing the SIS himself or by devolving the assessment to a supplier or system integrator. However, the user retains overall responsibility.

The requirements of 61508 and 61511 for “proven in use” are very demanding. The user is required to have appropriate evidence that the components and subsystems are suitable for use in the SIS. This means that as a minimum the user must have:

- A formal system for gathering reliability data that differentiates between safe and dangerous failures
- Means of assessing the recorded data to determine the safety integrity of the device / equipment, and its suitability for the intended use.
- Evidence that the application is clearly comparable
- Recorded historical evidence of device hours in use
- Evidence of the manufacturer’s management, quality and configuration manufacturing systems
- Device firmware revision records
- Proof that reliability data records are updated and reviewed regularly

R

Rail-mount
Thin rectangular transmitters that are typically attached to a DIN-rail (G-rail or top-hat rail) or fastened directly onto a surface. (See 3.1.10.3)

Response Time
The Response Time of a sensor is the time required for the output of a sensor to change by a specified percentage of an applied step change in temperature for a specific set of conditions. (See 3.2.3.8)

RFI – Radio Frequency Interference
This interference is at the higher end of the electromagnetic interference (EMI) scale and emanates from most types of radios, TV broadcast antennas, radar antennas, routers and some cell phones. Many field transmitters use sophisticated filtering to prevent this noise from impacting the measurement.

Root Sum Squares Technique
The square root of the sum of the squares (RSS) can be used to calculate the aggregate accuracy of a measurement when the accuracies of the all the measuring elements are known. The average accuracy is not merely the arithmetic average of the accuracies (or uncertainties), nor is it the sum of them.

RTD - Resistance Temperature Detector
Sometimes referred to as Platinum Resistance Thermometers (PRT) . They are based on the principle that the electrical resistance of a metal increases as temperature increases – a phenomenon known as thermal resistivity. (See 3.2.3)

RTD accuracy
There are several classes of RTD accuracy / interchangeability that define the relationship of the amount of error allowed for a given RTD type at a given temperature as compared to the standard. Refer to Figure 3.2.11a. The maximum allowable sensor interchangeability error at a given process temperature is defined by the two IEC 60751 standard classifications; Class A and Class B. (See 3.2.11)

Redundancy
Refers to using multiple sensors and/or multiple transmitters to add reliability to a measurement. (See 3.1.2.3)

Reference element
Curve utilized within a transmitter to stabilize sensor inputs.

Remote Mount
Transmitter is mounted reasonably near but not directly onto a sensor. This is the preferred method where the measurement point is inaccessible or process environment at the measuring point is adverse. (See 3.1.10.2)

Repeatability
The repeatability of a measurement system, also called precision, is the degree to which repeated measurements under unchanged conditions show the same results. (See 3.1.4.1.2)

Resolution
The smallest change in the underlying physical quantity that produces a response in the measurement.

Reliability
A measure is said to have a high reliability if it produces consistent results under consistent conditions. (See 4.2.8)

Repeatability
The repeatability of a measurement system, also called precision, is the degree to which repeated measurements under unchanged conditions show the same results. As an example, an instrument could present the same value for temperature every time (under the same measurement conditions) but the value is offset from the correct value. This is repeatable but not accurate. The ideal measurement therefore would be both accurate and repeatable. (See 3.1.4.1.2)

Response Time
The amount of time required for a temperature change in the measured media to be reflected by the sensor output or a transmitter's output.

Response time is the sensor's ability to react to a change in temperature, and depends on the sensor's thermal mass and heat transfer from the material being tested. For instance, an RTD probe in a thermowell will react much more slowly than the same sensor immersed directly into a fluid. A spring loaded sensor with thermally conductive fluid responds twice as fast as one with a free hanging sensor with no fill in the same assembly. (See 3.2.3.8)

A sensor's dynamic response time can be important when the temperature of a process is changing rapidly and fast inputs to the control system are needed. A sensor installed directly into the process will have a faster response time than a sensor with a thermowell.

S

Safety Certified Transmitters
A transmitter to be used for a safety function in an SIS must meet certain design and performance criteria and be certified for use in accordance with IEC 61508 or IEC 61511. (See 8.3)

Safety Requirements Specification (SRS)
Per IEC 61511 it is a specification that contains all the requirements of the safety functions that must be performed by the safety instrumented system. Its objective per IEC 61511 is to specify all of the requirements of safety instrumented systems needed for detailed engineering and process safety information purposes. (See 8.3)

Sample time
Frequency with which a transmitter processes inputs from a temperature sensor and updates the output signal.

Seebeck effect
According to the Seebeck effect, a voltage measured at the cold junction is proportional to the difference in temperature between the hot junction and the cold junction. This voltage may be referred to as the Seebeck voltage, thermoelectric voltage, or thermoelectric emf.

Self-diagnostics
Also called Internal Diagnostics – diagnostics in a microprocessor-based transmitter that monitor transmitter memory and continuously examine its own performance and verify output validity.

Self Heating
Heating is caused when the sensing current from the transmitter is passed through an RTD sensing element. Since the current supplied by the transmitter is very small (typically 150-250 µamps) heat produced is also very small and will be dissipated in the flowing process medium and contribute a negligible measurement error. Note that older analog circuitry transmitters use a much higher excitation current and produce far more heat causing a significant error.

Secondary Standard
A general term used to refer to a calibration standard that is traceable to a higher level. All calibrations should be performed traceable to a nationally or internationally recognized standard like NIST in the USA. There may be many levels of traceability between your shop and NIST but the trail should exist and the tolerance of the standards fully understood.

Sensing Element
The sensing element responds to temperature by generating a measureable resistance change (RTD) or voltage signal (T/C) that changes as the temperature changes.

Sensitivity
The ratio of the size of the response of a measuring device to the magnitude of the measured quantity change.

Sensor
See Sensing Element

Sensor Interchangeability Error
See Interchangeability error

Sensor Response Time
The Response Time of a sensor is the time required for the output of a sensor to change by a specified percentage of an applied step change in temperature for a specific set of conditions.(See 3.2.3.8)

Sensor Sheath
A tube made of metal, usually stainless steel, into which a sensing element is placed, lead wires are connected, insulation is added, the tip is welded shut and a hermetic potting seal is placed at the end where the wires emerge. (See 3.2.3.1.2)

SIF
Safety Instrumented Function - Is defined as a function to be implemented by a SIS which is intended to achieve or maintain a safe state for the process with respect to a specific hazardous event. A SIF is a single set of actions and the corresponding equipment needed to identify a single hazard and act to bring the system to a safe state. (See 8.3)

SIL - Safety Integrity Levels
As defined in part 4 of the IEC 61508 standard, is "the likelihood of a safety-related system satisfactorily performing the safety functions under all the stated conditions, within a period of time". A safety integrity level is further defined as "a discrete level (one of four) for specifying the safety integrity requirements of safety functions." (See 8.3)

SIS- Safety Instrumented System
Is defined by the IEC 61511 Safety Standard as an instrumented system used to implement one or more safety instrumented functions. An SIS is composed of any combination of sensors, logic solvers, and final elements. (See 8.3)

Specification Sheets
Are the basis for ordering instruments, so they must contain all the dimensions and other information needed by a manufacturer to configure each component to function according to the design and the demands of the process.

Spring Loaded
A spring located in the threaded adaptor allows the capsule to travel, ensuring contact with the bottom of a thermowell. This spring style provides continuous contact in high vibration applications and significantly faster speed of response of the measurement. (See 3.2.3.3.2)

Stability
The ability of the transmitter to overcome drift in order to maintain accuracy over time. It is related to the sensor's measurement signal, which can be influenced by humidity and prolonged exposure to elevated temperatures. Stability is maintained by using reference elements in the transmitter to stabilize sensor input. (See 3.2.3.13)

Stem Conduction
See Conduction error

Surface Mounting
An efficient and convenient installation method when a thermowell installation is not possible or appropriate. Sensors can be mounted with adhesives, screws, clamps, magnets or welds. Good thermal contact with the process surface is necessary as well as preventing heat loss by using a good thermal insulation over the sensor and its connecting wires. (See 3.2.3.5.2)

T

TCR - RTD elements are characterized by their Temperature Coefficient of Resistance (TCR) also referred to as its alpha value. The IEC 60751-2008 standard defines these values for different element types. (See 3.2.3.6.1)

Thermal Conductivity
Heat transfer across materials of high thermal conductivity occurs at a higher rate than across materials of low thermal conductivity. In temperature measurement it infers that a spring loaded sensor in contact with the thermowell will have faster heat transfer than if it were in an air gap and therefore faster response. It also infers that sensors in a liquid will have a faster response than those in a gas.

Thermal Resistivity
The principle that the electrical resistance of a metal increases as temperature increases

Thermocouple (T/C)
A thermocouple (T/C) is a closed-circuit thermo-electric temperature sensing device consisting of two wires of dissimilar metals joined at both ends. A current is created when the temperature at one end or junction differs from the temperature at the other end. This phenomenon is known as the Seebeck effect, which is the basis for thermocouple temperature measurements. (See 3.2.4)

Thermocouple Accuracy
Thermocouple accuracy is influenced by several factors including the T/C type, its range of interest, the purity of the material, Electrical noise, corrosion, junction degradation, and the manufacturing process. T/Cs are available with standard grade tolerances or special grade tolerances called Class 2 and Class 1 respectively. The most common controlling international standard is IEC-60584-2. The most common U.S. standards are ISA-MC96.1 and ASTM E230. Each standard publishes limits of tolerance for compliance. (See 3.2.4.8)

Thermocouple Types
There are many thermocouple types each made from different combination of metals or metal alloys. They include types E, J, K, T, R, S, B and N. (See 3.2.4)

Thermocouple Response Time
For bare probes or exposed tip designs T/Cs are significantly faster – 2 to 5X – than bare RTD probes. However, since the vast majority of industrial measurements are made using thermowells the time response for T/Cs and RTDs is about equal.

Thermocouple Degradation
Thermocouple junctions of two dissimilar metals begin to degrade over time at a rate largely dependent on the temperature they are exposed to and corrosive elements in their surrounding environment. (See 3.1.6.8)

Thermowell
Thermowells are most often constructed from machined barstock in a variety of materials and may be coated with other materials for erosive or corrosive protection. They are available with threaded, welded or flanged connections. See also Protection Tubes.

Thermowell Mounting Methods
(See 4.2.2.2.3)

- ***Threaded -*** Provides for easy installation and removal. Not suited to high pressure applications.
- ***Flanged -*** Flanges are bolted into place, providing secure installation for high pressure, high velocity, high temperature applications and corrosive processes.
- ***Welded -*** Permanently installed for no-leak high pressure ratings.

Thermowell Standards
ASME PTC 19.3TW - 2010 is internationally recognized as a mechanical design standard yielding reliable thermowell service in a wide range of temperature measurement applications. It includes evaluation of stresses applied to a barstock thermowell as installed in a process based on the design, material, mounting method, and the process conditions. (See 3.3.7.1)

Thin-film Elements
Are manufactured by depositing a thin film of pure platinum on a ceramic substrate in a maze-like pattern. Refer to Figure 3.2.3.2.3a The sensor is then stabilized by a high temperature annealing process and trimmed to the proper R0 value. These compact sensors are then encapsulated with a thin glassy material. For many applications they have superior resistance to vibration. (See 3.2.3.2.3)

Three-wire RTD
In a three-wire configuration, compensation is accomplished using the third wire with the assumption that it will be the same resistance as the other two wires and the same compensation is applied to all three wires. However, in the real world there will always be some difference due to wire manufacturing irregularities, unequal lengths, loose connections, work hardening from bending, and terminal corrosion. (See 3.2.3.1.3.1)

Threaded Style
A capsule style sensor probe with the threaded adaptor to provide a connection to the process and connection head or housing. Can also refer to a threaded connection for a thermowell to the process.

Time Constant
The Time Response of a sensor is the time required for the output of the sensor to change by 63.2% of the step change in temperature while in water moving at 3 ft/sec. The Time Constant is the time required for a sensor at 0° that is then thrust into 100 °C water flowing at 3 fps to reach 63.2 °C.

Total Probable Error (TPE)
A calculation that reflects the probable error of the transmitter and sensor system, based on anticipated installation conditions. The components of this calculation include the root sum square of the multiple transmitter accuracy effects. (See 4.2.7)

Traceability
All calibrations should be performed traceable to a nationally or internationally recognized standard. The standards used for calibration should be traceable to a National Metrology Institute like NIST in the USA. There may be many levels of traceability between your shop and NIST but the trail should exist and the tolerance of the standards fully understood. (See 5.7.3)

Transient Protection
Many transmitters offer transient suppression options that can be integrally mounted onto the terminal strip within the housing. For other transmitters an external protection device may be used. (See 3.1.6.3)

Transmitter
An instrument capable of receiving low-level inputs from temperature sensors (Typically RTDs and T/Cs); filtering, conditioning, and converting the signal and communicating a robust accurate and stable analog or digital output to the receiving system.

Two-wire RTD
In a two-wire configuration there can be no compensation for lead wire resistance since the lead wires are in series with the probe resistance and appear to the transmitter as part of the sensor causing an inherent accuracy degradation. There are few, if any, applications where two wire sensors are a good choice.

U

Ungrounded Junctions
Exist when the T/C elements are not connected to the sensor sheath but are surrounded with insulating MgO powder. Ungrounded junctions have a slightly slower response time than grounded junctions but are less susceptible to electrical noise. (See 3.2.4.3.1)

Universal Field Calibrator
Universal field calibrators are available in a variety of models from several major suppliers. Many models are HART compliant and others also interface with FOUNDATION™ fieldbus and Profibus PA.

They have the ability to simulate RTD, T/C, mv, voltage, and frequency signals that may be connected to a transmitter for calibration purposes. Many provide a dual screen capability to simultaneously see the simulated signal and the transmitter output. Some also have the ability to read signals from sensors and display the actual value of the variable. (See 5.7.5.2)

Update rate
Frequency of sampling by a transmitter from a sensing element.

Uncertainty
The lack of certainty of the validity of the value being presented.

V

Vibration
Most thermowell failures are caused by fluid induced vibration associated with Vortex Shedding. Wake frequency calculations should be performed to verify design parameters of each thermowell. (See chapter 9)

Vortex Shedding
When fluid flows past a thermowell inserted into a pipe or duct, vortices form at both sides of the well and these vortices detach, first from one side, and then from the other in an alternating pattern. This phenomenon is known as vortex shedding, the Von Karman Vortex Street or flow vortices. (See 3.3.7.1)

W

Wake Frequency Calculations
Complex calculations required to select the proper thermowell design for a given application. Typically implemented in a “tool” used by a thermowell supplier and are defined in ASME PTC 19.3 TW-2010. Consideration is given to all of the flow parameters including pressure, temperature, flow rate , fluid viscosity and rangeability. (See 9.1)

WirelessHART™
WirelessHART™ is an open-standard wireless networking technology developed to complement the existing HART standard. The protocol was defined specifically for the requirements of process field device networks and utilizes a time synchronized, self-organizing, and self-healing mesh architecture. (See 3.1.3.5)

Wire-wound
Wire-wound RTDs are manufactured either by winding the resistive wire around a ceramic mandrel or by winding it in a helical shape supported in a ceramic sheath – hence the name wire-wound. (See 3.2.3)

Worst Case Error (WCE)
The largest possible error expected under the anticipated conditions. These calculations are a summation of the raw values of reference accuracy, digital temperature effect, and ambient temperature effects on the input and output. (See 4.2.7)

Recommended retail price $35.99

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