Overview

Introduction

Several methods of temperature measurement and control have been developed over the years. Industrial process control usually requires that the temperature sensing device must be remote from the measuring or controlling instrument. Of the various thermal sensing devices, the thermocouple is most commonly used, offering the best compromise of cost, accuracy and reliability.

We are a leading manufacturer of thermocouples. Our modern production facilities and years of experience allow us to provide the highest quality sensors at competitive prices.

Warning

Hazardous extraneous voltage capable of causing severe injury or death may exist between thermocouple leads and ground. Disconnecting the instrument power may not remove this voltage. Measure for the presence of voltage between each sensor lead and ground before servicing.

Thermocouple Assemblies

A thermocouple assembly generally has four major components:

Element

Two wires of dissimilar alloys joined at the tip. When the ends are exposed to a temperature gradient, and electromotive force (EMF) is generated. The EMF is very small, amounting to microvolts per degree.

Protection Tube

A metal or ceramic tube, usually closed at the end, that protects the element from the environment of the process.

Head or Cold End Termination

The head is a terminal block/protective enclosure assembly provided for connection to thermocouple extension wire. In lieu of this, an integrated extension assembly may be provided.

Extension Wire

Although not a portion of the thermocouple assembly itself, the extension wire is a critical part of the total circuit. The wire must be manufactured from alloys compatible with the element.

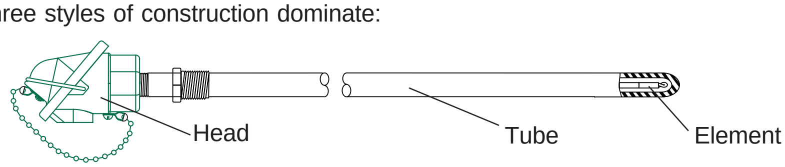
In addition, various mounting devices or attaching devices are offered for most assemblies.

Construction Styles

The industry adage “if you ain’t got it, invent it” applies. Thermocouples have been manufactured in endless combinations of construction. While no supplier can meet 100% of all customer requirements, we offer one of the widest varieties of thermocouple assemblies in the industry.

Three styles of construction dominate:

Tube and Element



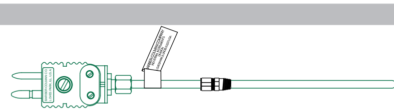
The protection tube, head and element are discrete components. The element is manufactured with individual conductors welded together at the tip. Element wires are separated by ceramic insulators. The protection tube can be thin wall tubing, schedule 40 pipe, ceramic or cast iron. Cold end termination is usually with a head and terminal block assembly.

Noble metal thermocouples are often supplied with two or more protection tubes. The tube in contact with the element must be ceramic; the outer tube can be either ceramic or metal.

Overview

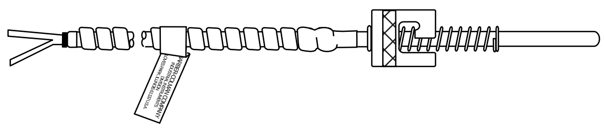
Construction Styles (continued)

BARCOPAC®



BARCOPAC is the Barber-Colman trade name for our magnesium-oxide (MgO) insulated thermocouples. This style consists of element conductors in magnesium oxide insulation with a stainless steel or Inconel sheath. The assembly is then drawn to the finish diameter. This form of construction compacts the insulation around the conductors. The result is a thermocouple with superior performance and longevity. The material can be bent to nearly any desired shape without damaging the element. Diameters of 0.040” to 0.250” are available.

Bayonet



The element is made from fiberglass insulated wire in a stainless steel protection tube. Usually the element is brazed to the tube at the tip. Mounting is with a twist-lock fitting commonly referred as a bayonet adapter. This form of construction is sometimes known as a “plastic style” because of its heavy usage in the plastics industry.

Alloy Selection

A thermocouple element consists of two wires of dissimilar alloys joined at the tip. When the ends of the elements are exposed to a temperature difference, an EMF is generated along the entire length of the element. The EMF level is dependent on the amount of temperature difference and the type of alloys used.

Alloy combinations have been developed to meet specific requirements. Each alloy set has certain characteristics (cost, temperature range, corrosion, resistance, etc.) that provide advantages for specific applications.

To simplify selection and provide uniformity, several alloy combinations have had single letter codes assigned by ANSI (American National Standards Institute) to designate particular types of thermocouples. For example, Type J for Iron vs. Constantan, Type K for Chromel vs. Alumel, and Type R for Platinum vs. Platinum/13% Rhodium.

Each alloy set has a unique EMF output for a given temperature. The measuring instrument is calibrated for a specific type thermocouple. When specifying replacement thermocouples, the element is typically the same type as the original.

Elements are classified into three groups:

Elements, Base Metal

Main advantages are economical cost, good reliability and reasonable accuracy. Use primarily for low to moderately high temperature range (-200° to 1700°C). Over 90% of all thermocouples are in this group. Types J and K prevail.

Type E, Chromel vs. Constantan.
Suitable for use from -200 to 871°C. Can be applied in atmospheres ranging from vacuum to mildly oxidizing. Excellent choice for cryogenic applications. Has the highest EMF per degree of all the common elements.

Overview

Alloy Selection (continued)

Type J, Iron vs. Constantan
The standard selection for use from 0° to 600°C. Type J has good reliability at lower temperatures. The positive leg will oxidize rapidly above 500°C. Very economical. Used extensively in the plastics industry but applicable to almost any process within its operating range. Available in a wide variety of construction styles.

Type K, Chromel vs. Alumel
Type K is the industry standard for use up to 1250°C. While stable in oxidizing atmospheres, it is prone to corrosion in reducing environments. Protection tubes are always recommended.

Type N, Nicrosil vs. Nisil
Similar to Type K but more resistant to oxidation and less subject to large drift in the EMF that is found in the positive Type K thermocouples operating at approximately 500°C.

Type T, Copper vs. Constantan
Suitable for use from -200° to 350°C, Type T is widely used in the food processing industry. More stable than Types E or J for low temperature applications. Has been used down to -269°C (boiling helium).

Elements, Noble Metal

Elements manufactured from noble metals offer improved accuracy and stability over base metals. Most are manufactured from combinations of Platinum and Rhodium. Commonly used in high temperature applications up to 1700°C. Also applied as reference standard when testing base metal elements. Highest cost of all thermocouples.

Type R, Platinum vs. Platinum/13% Rhodium
Type R has long been the industrial standard noble metal alloy used for high temperature applications to 1450°C. Platinum is prone to contamination if in contact with other metals. Ceramic protection tubes must be used. Very stable in an oxidizing atmosphere but will degrade rapidly in vacuum or a reducing atmosphere.

Type S, Platinum vs. Platinum/13% Rhodium
Applications and conditions similar to Type R. Type S was applied as the “laboratory thermocouple” while Type R was considered the “industrial thermocouple.” This practice was based on tradition. Type S is not being used extensively as an industrial sensor.

Type B, Platinum/6% Rhodium vs. Platinum/30% Rhodium
Applications and considerations similar to Types R and S, but useful to 1700°C. Very low output at low temperature. Also very non-linear at low end. Generally not considered usable below 250°C. More stable than R or S at high temperature. Must be protected in ceramic tube.

Elements Refractory Metal

Combinations of Tungsten and Rhenium. Very brittle and prone to breakage. Used for very high temperature applications up to 2300°C. Must be used in vacuum or totally inert atmosphere.

Type C, Tungsten/5% Rhenium vs. Tungsten/26% Rhenium
May be used at temperatures up to 2315°C. Brittle and prone to breakage. Generally considered a limited life product. Element must not be in contact with metal. Tungsten has no oxidation resistance. These elements must be used in vacuum, hydrogen or totally inert gas. Sometimes supplied with open end protection tube for use with vacuum. Otherwise manufactured as a sealed assembly purged with argon.

Selecting the Element

When selecting the proper element for an application, consideration must be given to length of service, temperature, atmosphere, response time, and cost. Be certain the Type (J, K, R, S, T, etc) matches the instrument with which it will be used.

Overview

Limits of Error

ANSI Limits, Base Metal

Reference Junction 0°C (32°F)
Published in ANSI Circular
MC96.1–1975

Type	Temperature Range	Standard	Special
J	0° to 293°C (32° to 559°F)	±2.2°C (±4°F)	±1.1°C (±2°F)
	293° to 760°C (559° to 1400°F)	±0.75%	±0.4%
K or N	-200° to -110°C (-328 to -166°F)	±2%*	**
	-110° to 0°C (-166° to 32°F)	±2.2°C (±4°F)*	**
	0° to 293°C (32° to 559°F)	±2.2°C (±4°F)*	±1.1°C (±2°F)
	293° to 1250°C (559° to 2282°F)	±0.75%	±0.4%
T	-200° to -67°C (-328° to -89°F)	±1.5%*	**
	-67° to 0°C (-89° to 32°F)	±1°C (±1.8°F)*	**
	0° to 133°C (32° to 271°F)	±1°C (±1.85°F)	±0.5°C (±0.9°F)
	133° to 350°C (271° to 662°F)	±0.75%	±0.4%
E	-200° to -170°C (-328° to -274°F)	±1%*	**
	-170° to 0°C (-274° to 32°F)	±1.7°C (±3.1°F)*	**
	0° to 340°C (32° to 644°F)	±1.7°C (±3.1°F)	±1°C (±1.8°F)
	340° to 900°C (644° to 1652°F)	±0.5%	±0.4%

*Thermocouples and thermocouple materials are supplied to meet the limits of error specified for temperatures above 0°C. A thermocouple material may not conform to the published sub-zero limits of error for that material when purchased, unless conformance is agreed to between purchaser and supplier upon placement of order.
**Special limits of error for sub-zero temperatures have not been established. The following limits for Types E and T are useful to start discussion: 200° to 0°C – Type E: ±1°C or ±0.5%, whichever is greater; Type T – ±0.5°C or ±0.8%, whichever is greater. Sub-zero limits of error for Type J and sup-zero limits of error for Type K are not considered because of the characteristics of their materials.

ANSI Limits, Noble Metal

Reference Junction 0°C (32°F)
Published in ANSI Circular
MC96.1–1982

Type	Temperature Range		Standard (Greater of:)	Special (Greater of:)
B	870 to 1700°C	1598 to 3092°F	±0.5%	- -
R or S	0 to 1450°C	32 to 2642°F	±1.5°C or ±0.25%	±0.6°C or ±0.1%

In this table, the limits of error for each type of thermocouple apply only over the temperature range for which the wire size in question is recommended. These limits of error should be applied only to standard wire sizes. The same limits may not be obtainable in special sizes.

Limits of error apply to thermocouples as supplied by the manufacturer. The calibration of a thermocouple may change during use. The magnitude of the change depends on such factors as temperature, length of time, and conditions under which it was used.

Non-ANSI Limits, Noble Metal

Type	Temperature Range		Limits of Error	
W-W, 26% Re	0 to 427°C	32 to 800°F	±4.4°C	±8°F
	427 to 2316°C	800 to 4200°F	±1%	±1%
W, 5% Re-W, 26% Re	0 to 427°C	32 to 800°F	±4.4°C	±8°F
	427 to 2316°C	800 to 4200°F	±1%	±1%
W, 3% Re-W, 25% Re	0 to 427°C	32 to 800°F	±4.4°C	±8°F
	427 to 2316°C	800 to 4200°F	±1%	±1%

Overview

Element Temperature Limits

The following table shows the allowable temperature limits for commonly used thermocouples and RTDs. These limits apply to thermocouples in conventional closed end protection tubes. In any general recommendations of temperature elements, it is not practicable to take into account special cases. In actual operation there may be instances where the temperature limits recommended can be exceeded. Likewise, there may be applications where satisfactory life will not be obtained at the recommended temperature limits. However, in general, the temperature limits listed are such as to provide satisfactory element life when the wires are operated continuously at these temperatures.

Type	Gauge	°F Range	°C Range
J	8	-70 to 1400	-57 to 760
	14	-70 to 1100	-57 to 593
	20	-70 to 900	-57 to 482
	24	-70 to 700	-57 to 371
K or N	8	-70 to 2300	-57 to 1260
	14	-70 to 2000	-57 to 1093
	20	-70 to 1800	-57 to 982
	24	-70 to 1600	-57 to 870
T	14	-70 to 700	-57 to 371
	20	-70 to 500	-57 to 260
	24	-70 to 400	-57 to 200
E	8	-70 to 1600	-57 to 871
	14	-70 to 1200	-57 to 649
	20	-70 to 1000	-57 to 538
R or S	24	-50 to 2650	-46 to 1454
B	24	32 to 2650	-0 to 1454
0.00385 Platinum RTD		-70 to 450	-57 to 232
0.00391 Platinum RTD		-70 to 450	-57 to 232

Extension Wire

A common misconception is that the EMF is generated at the tip. The voltage is actually produced along the entire length of the element and is proportional to the temperature gradient from one end to the other. One end of the element is the junction at the hot end. The other end (cold junction) of the thermocouple is at the measuring/control instrument.

The extension wire between the measuring instrument and the thermocouple assembly is part of the thermocouple circuit. It will supply a portion of the EMF generated.

The extension wire must be compatible with the alloys used in the thermocouple. For base metal thermocouples the extension wire is usually constructed of the same alloys as the element. For noble metal elements, base metal alloys are selected to match the characteristics of the element within the operating range of 0° to 150°C.

Two types of wire are available: thermocouple grade and extension grade. Thermocouple grade wire is manufactured with alloys identical to the wire use for elements. Extension grade wire for base metal thermocouples is made with similar EMF properties at ambient temperature, but is not rated for accuracy at high temperature.

Insulation is the largest factor determining performance of extension wire. Moisture resistance, abrasion resistance, temperature rating and cost are factors to be considered.

Overview

Extension Wire (continued)

PVC has excellent moisture and abrasion resistance but is only rated to 105°C. Its low cost makes it a good choice for many applications.

Teflon and Kapton are alternatives to PVC when higher temperatures are encountered. Ratings as high as 315°C are available.

Fiberglass braided insulations have less moisture resistance, but temperature ratings up to 700°C are available.

Ceramic and Silica fiber have the highest temperature ranges but abrasion and moisture resistance are poor. Ceramic insulation rated at 1430°C is often used for furnace survey thermocouples.

ANSI Limits of Error

For extension wire

Type	Temperature Range	Standard
BX	0 to 100°C (32 to 200°F)	+0.0, -3.7°C (+0.0, -6.7°F)
SX & RX	0 to 200°C (34 to 400°F)	5.0°C (9.0°F)

Protection Tubes

Protection tubes are necessary to protect the element from contamination and physical damage. Size, shape and material vary with the application. Choices vary with the style of construction.

Bayonet style thermocouples are only available with stainless steel sheaths. This material has the durability required for the limited range of conditions encountered.

BARCOPAC thermocouples are offered in a variety of stainless steel alloys plus Inconel. Stainless steel has excellent resistance to corrosion but is limited to applications below 870°C.

Inconel has a high nickel content and is the preferred choice for applications to 1140°C. Typically, Type J assemblies are manufactured with stainless steel, and Type K uses Inconel.

Countless combinations of assemblies manufactured from discrete element and protection tubes exist. We offer a selection of styles designed to meet the requirements of a broad range of applications. Protection tubes are available in metallic and non-metallic materials. The selection of material is dependent on the environment of the process. Generally, the larger diameter tubes offer better physical strength and longevity. They can also accommodate heavier gauge elements. The benefit of larger tubes must be weighed against the added cost of the material. In some cases, limited life material may be more cost effective than premium grade assemblies.

Metal

Low alloy material (black iron or welded steel pipe) is a good selection for application to non-corrosive environments. Advantages include low cost, excellent abrasion resistance and good physical strength. Deteriorates above 550°C in oxidizing atmosphere. Available in a variety of sizes.

Stainless steel offers improved resistance to corrosion over welded steel pipe. It has good strength and stability to 870°C (446 SS is rated to 1100°C). Available in a variety of alloys and sizes. Cost varies from moderate to high depending on specific alloy selected.

Inconel is the choice for application in highly reducing atmospheres operating at higher temperatures than stainless steel. Has excellent strength and resistance to corrosion up

Protection Tubes (continued)

to 1150°C. We offer alloy 601 which has superior characteristics than commonly used alloy 600. Cost is higher than most stainless steels. Available in 1/2" or 3/4" NPT schedule 40 pipe. Inconel 600 thin wall tubing is also available.

Ceramic

Ceramics can tolerate high temperatures than any metal pipe. They can often withstand corrosive environments too extreme for the best stainless alloys. All ceramics lack the resilience of metal and are prone to breakage.

Mullite, also know as porcelain, is a good choice for base metal thermocouples. Advantages include moderate cost, good thermal conductivity and good resistance to thermal shock. Has less physical strength than alumina. Recommended for use below 1450°C.

Alumina has greater strength than Mullite and can be applied at higher temperatures. Use is typically restricted to noble metal thermocouples though it may be applied to base metal because of its corrosion resistance. Has less resistance to thermal shock than Mullite.

Silicon Carbide offers greater corrosion resistance than any commonly offered metal or ceramic material. Excellent thermal conductivity and resistance to thermal shock. Very brittle. Extreme care must be taken to prevent physical shock.

Resistance Temperature Detectors

RTDs are thermal sensors that change resistance with temperature. The amount of change is dependent on the change in temperature and the specific alloy of the conductor. In certain applications, an RTD is a better choice than a thermocouple.

RTDs are more accurate than thermocouples – especially over a narrow temperature range. Standard accuracy ratings of 0.25% and 0.10% are offered.

The RTD sensing element is a coil of wire – precision wound to a specific resistance value. The element is hermetically sealed in glass to prevent influence from moisture. This element is then mounted in the tip of a metal protection tube for physical protection. Physical configuration of the complete assembly is similar to a thermocouple.

RTDs have been manufactured from several alloys, including copper, nickel and platinum based material. We supply platinum based units in two different coefficients.

The primary advantage of using an RTD is greater accuracy. Disadvantages include higher cost and less resistance to physical shock. Since the element has greater mass, the RTD will respond slower than a thermocouple. The decision to us an RTD versus a thermocouple has to be based on these factors.

Resistance Coefficient

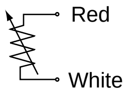
The change in resistance per degree (resistance coefficient) depends on the specific alloy content of the wire. In past years, several coefficients were marketed. Most U.S. manufactured RTDs had coefficients near 0.00391Ω/Ω/°C. Industry has now standardized on the DIN (Deutsche Industrie-Norm) specification of 0.00385Ω/Ω/°C. We can supply either sensor.

Overview

RTD Configurations

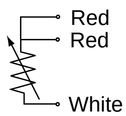
If a sensor relates resistance to temperature, then the resistance of the lead wire can affect the accuracy of the reading. Various methods have been developed to compensate. This has resulted in RTDs being manufactured in two wire, three wire and four wire configurations.

Two Wire



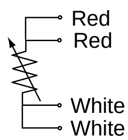
The two wire element has no provision for lead wire compensation other than increasing the size of the lead wire. It is suitable for installations where the distance to the measuring instrument is short, or accuracy is not critical.

Three Wire



The three wire configuration is the industry standard. Two red wires are tied together at the element. The white wire is terminated at the other end of the element. The measuring instrument can sense the resistance of the two red wires, and subtract this from the resistance between one red wire and the white wire. This is accurate as long as all three leads are the same length and gauge.

Four Wire



Four wire RTDs have two wires terminated at each end of the element. Current to the sensor is supplied on one wire, and the voltage value is measured on the other. Since there is no current flowing in the measuring wires, no error is contributed by lead wire resistance. Four wire sensors are usually restricted to laboratory environments.

General Specifications

Element — Platinum wire, 100 Ω at 32°F (0°C). Temperature coefficient of resistance for the range of 0 to 100°C (32 to 212°F) is 0.00385 Ω/Ω/°C, DIN 43760 (0.00391 Ω/Ω/°C also available).

Repeatability — ±0.18°F or better over full range

Stability — Drift is less than ±0.18°F at 32°F after one year normal service within rated temperatures

Time Constant — Five seconds in water at three feet per second

Self Heating — 28 mW/°F in water at three feet per second

Vibration — Assembly construction withstands 50 Hz to 2000 Hz at 20 G's minimum MIL STD 202C, method 204A, test condition D

Shock — Element construction withstands minimum 100 G's sine wave shock of eight milliseconds duration, three blows applied to each axis

Intermediate Temperature
Range: -148 to 500°F (-100 to 260°C)
Insulation Resistance: 100 MΩ minimum at 50 Vdc.
Leads: AWG #22, strand nickel plated copper wire. Teflon insulated

High Temperature
Range: -148 to 932°F (-100 to 500°C)
Insulation Resistance: 10 MΩ minimum at 50 Vdc.
Leads: AWG #22, strand nickel plated copper wire. Fiberglass insulated

Protection Tube Materials

304 stainless steel. Good oxidation and corrosion resistance in a wide range of industrial environments. Subject to carbide precipitation which can reduce corrosion resistance in the 800 to 1000°F range. Good mechanical properties from -300 to 1450°F. Regarded as the standard protection tube material.

316 stainless steel. Same areas of application as 304 stainless steel. Improved resistance to mild acid and pitting corrosion.

Overview

Specifications (continued)

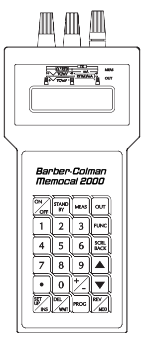
Accuracy

Accuracy tolerances for RTD with ±0.10 or ±0.25% rating.

Rating	Tolerance	Temperature °F										
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
0.25%	± °**F**	1.02	1.07	1.33	1.80	2.44	3.05	3.74	4.26	5.08	5.62	6.21
	± **Ohms**	0.21	0.23	0.28	0.38	0.50	0.61	0.73	0.83	0.94	1.04	1.15
0.10%	± °**F**	0.32	0.37	0.57	0.81	1.12	1.40	1.75	2.00	2.43	2.60	3.20
	± **Ohms**	0.07	0.08	0.12	0.17	0.23	0.28	0.35	0.39	0.45	0.49	0.57

Hand Held Calibrator

MEMOCAL 2000



The Barber-Colman MEMOCAL 2000 is a lightweight, versatile, hand-held calibrator for use both in the field and laboratory. The small size, simple programming, friendly interface, high noise immunity and long battery life make the MEMOCAL ideal for field maintenance calibration (Reference Accuracy to 0.015%). The optional leather carrying case features an over the shoulder strap and allows for viewing of both the display and the keypad. The high accuracy, large range of I/O capabilities and digital interface make the MEMOCAL ideal for laboratory use. A standard 120/240 Vac adapter saves battery capacity when working at the bench.

The MEMOCAL 2000 simulates and measures 15 different thermocouple, 2 RTD, mA, mV, voltage and ohm signals. A built-in 24 Vdc power supply allows excitation and measurement of 2-wire and 4-wire transmitters. Standard features also include configurable internal or external cold junction compensation, square root extraction and quadratic signal generation.

Up to 50 program steps can be created in one or more programs, providing pre-configured ramp, soak and step functions for calibration zero, span and midpoints. Two dry contact inputs allow program advance and hold.