Burns Engineering

Thermocouples

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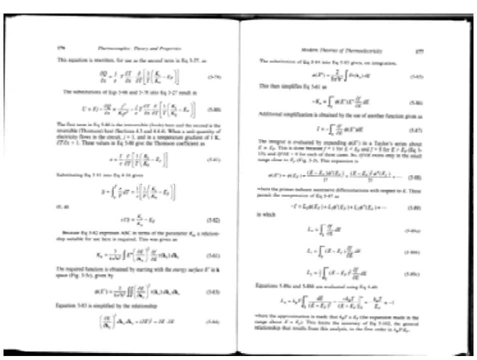
Agenda

Thermocouples
- Basic Operation
- Types
- Temperature Range
- Performance
- Sensor Selection
- Typical Applications
- Failure Modes
- Calibration
- Construction Types

Thermocouples

Here's what we won't be talking about

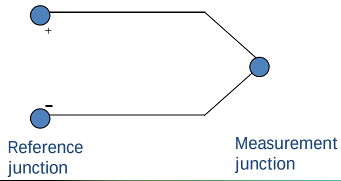


"Thermocouples Theory and Properties" Daniel D. Pollock 1991

The thermocouple is a very simple device mechanically, just two wires welded together. It's the relationship between the voltage and temperature which gets really complicated as shown here.

Basic Operation

- A thermocouple consists of two dissimilar conductors in contact, which produce a voltage when there is a difference in temperature between the reference junction and the measurement junction. The size of the voltage is dependent on the difference of temperature of the junction to other parts of the circuit.
  - 5 to 6 mV @ 100°C
  - Voltage changes with change in temperature
  - Requires reference (cold) junction compensation – typically handled by the measurement electronics



This is a type K thermocouple in a common configuration. Ceramic tubes insulate the wires.

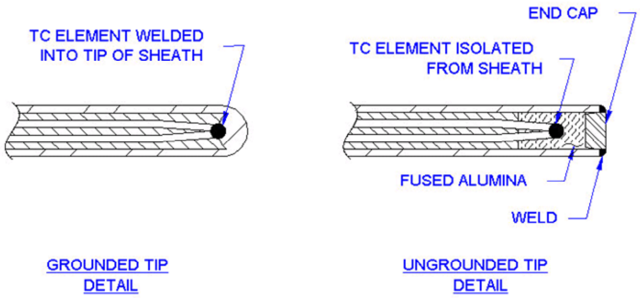
Thermoelectric Effect

- Seebeck Effect
  - Direct conversion of temperature differences to electric voltage and vice-versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it a temperature difference results.

Thermocouples

Types

- Junctions can be grounded, ungrounded or exposed

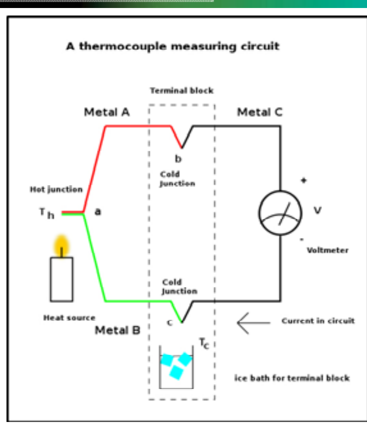


An ungrounded junction is the most common configuration. It provides electrical isolation from the probe sheath making it less susceptible to interference from RFI or EMI. A grounded junction is used when fast response or high tip sensitivity is required.

Exposed Junction

An exposed junction can be used for moderate temperatures where the fastest response time is required. They are not recommended for high temperatures or in corrosive atmospheres because the junction can become contaminated very quickly resulting in an inaccurate temperature measurement.

Thermocouple Circuit



http://en.wikipedia.org/wiki/File:Thermocouple_circuit.svg

Thermocouples

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Types

- Most common — ANSI color code
  - Type T: Copper-Constantan — Red/Blue
  - Type J: Iron-Constantan — Red/White
  - Type E: Chromel-Constantan — Red/Purple
  - Type K: Chromel-Alumel — Red/Yellow

- High temperature types
  - R, S, B Platinum/Platinum-Rhodium — 2640°F
  - W3, W5 Tungsten/Tungsten-Rhenium — 4200°F
- Each type has a different temperature range and Voltage vs. Temperature relationship

The most common types of thermocouples, also referred to as base metal types, are J, K, T, and E. Each has a unique V vs. T relationship and is identified by the lead wire color codes.

High Temperature Thermocouples

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Types B, R, and S thermocouples use platinum or a platinum–rhodium alloy for each conductor. These are among the most stable thermocouples, but have lower sensitivity than other types, approximately 10 µV/°C, so are usually used only for high temperature measurements due to their high cost and low sensitivity.

B

Platinum–Rhodium alloy for each conductor. One conductor contains 30% rhodium while the other conductor contains 6% rhodium. Usage up to 1800 °C.

R

Platinum–Rhodium alloy containing 13% rhodium for one conductor and pure platinum for the other conductor. Usage up to 1600 °C.

S

Platinum-Rhodium alloy containing 10% Rhodium (the positive or "+" wire) and a second wire of 100% platinum. Usage up to1600 °C.

Low Temperature Thermocouple

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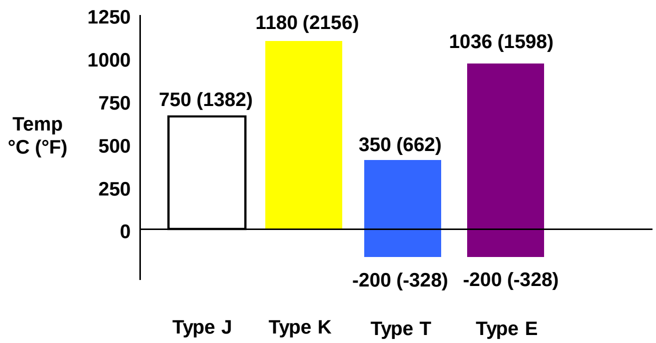
Chromel - gold/iron thermocouple

- Positive wire is chromel and the negative wire is gold with a small fraction of iron.
- Cryogenic applications (1.2–300 K). Both the sensitivity and the temperature range depends on the iron concentration. The sensitivity is typically around 15 µV/K at low temperatures and the lowest usable temperature varies between 1.2 and 4.2 K.

Temperature Range



Performance

Specifications

- Built to ASTM E-230 and ANSI MC 96.1
- Sheath material is typically 316 SS on type T, J, E and Inconel 600 on type K to handle the higher temperatures
- Special or standard limits of error
- Specialty types are available with custom tolerances and performance

There are also international standards that define the various thermocouple types. A Google search will quickly identify all that apply.

Performance

Temperature Range & Initial Calibration Tolerances			
Thermocouple Type	**Temperature Range**	***Standard Limits** greater of	***Special Limits** greater of
T	-200°C to 350°C	± 1.0°C or ± 0.75%	± 0.5°C or ± 0.4% **
J	0°C to 750°C	± 2.2°C or ± 0.75%	± 1.1°C or ± 0.4%
E	-200°C to 870°C	± 1.7°C or ± 0.5%	± 0.5°C or ± 0.4% **
K	0°C to 1180°C	± 2.2°C or ± 0.75%	± 1.1°C or ± 0.4%
* % applies to temperature measured in °C			
** -200°C to -170°C error is 0.8%			

In addition to the standard and special limits of error there are specialty thermocouples that have higher accuracies. Careful selection of the wire and manufacturing techniques control the thermoelectric properties.

Selection

Selection Considerations

- Accessories
- Temperature
- Durability
- Time response
- Signal conditioning
- Low cost – use caution here – accuracy, lead wire, can greatly add to the cost.

Besides the thermocouple sensor, there are several accessories available to protect and adapt the thermocouple to various applications. We'll look at how these can be used to achieve the measurement accuracy and durability desired.

Selection

Accessories

- Thermowells
- Connection head and terminal block
- Transmitter
- Extension wire and connectors

Selection

Accessories

- Thermowells
  - Temperature/pressure
  - Corrosion resistance
  - Process connection
  - Wake frequency and strength calculation

Thermowells protect the immersed portion of the sensor from corrosion, erosion, high flow rates, or high drag that may be present in processes. Consideration needs to be given to temperature, pressure, and flow rates when selecting a thermowell.

Selection

Accessories

- Connection head and terminal block
  - Hazardous atmosphere – usually requires complete assembly to be rated
  - Terminal block terminals do not have to match the thermocouple conductor material IF they are at the same temperature.

Protection of the thermocouple external to the process also needs to be given careful consideration. A connection head provides protection for the lead wire seal and can contain a terminal block, transmitter, or temperature indicator. In the case of a hazardous atmosphere, an explosion proof head and rated thermocouple assembly can be specified.

Selection

Accessories

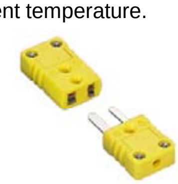
- Transmitter
  - Most transmitters have options for several thermocouple types
  - Locate transmitter as close as possible to the thermocouple to minimize extension wire length. Thermocouples are easily affected by RFI/EMI.

If the thermocouple is located a long distance from the control equipment, then a transmitter can be a beneficial addition to the measurement loop. It provides a more robust signal that is less susceptible to interference from RFI, EMI, or other stray voltage.

Selection

Accessories

- Extension wire and connectors
  - Extension grade wire – match thermocouple type
  - Two common types of connectors are called standard and mini. The standard has round pins and the mini has flat pins. Contacts may match the thermocouple type or may be plated brass or similar material. This will not introduce an error unless the contacts are at a different temperature.



A connector is a low cost solution to enable a quick disconnect from a display or other device. Box mounted receptacles are also available and can be configured in a high density pattern where multiple inputs are desired.

Selection

Performance

- Process characteristics/needs
- Environment
- Cost considerations

Next we'll look at some of the more important process characteristics and the ambient conditions to see how they affect the selection of a thermocouple.

Selection

Performance

Consideration	Thermocouple
Accuracy at 32°F	Standard limits: ± 4°F* Special limits: ± 2°F*
Calibration	Limited to in-situ calibration
Stability	Dependent on wire homogeneity and process conditions
Repeatability	Highly dependent on process characteristics

*Types J and K. Types T and E special limits are ± 0.9°F

The most common question is "what is the accuracy?" Accuracy includes many variables some of which are in the sensor and others are related to how the sensor is installed in the process.

Start first with the sensor and choose an accuracy grade that fits your needs. Unless it's an unusually low accuracy requirement for the process, the highest accuracy grade "special limits" is a good choice.

Calibration of a thermocouple is usually limited to in-situ by comparison to a standard. This is due to the lead wire and other connections having an effect on accuracy. Disconnecting them and testing only the thermocouple leaves out potential error sources.

Selection

Process Characteristics

Consideration	Thermocouple
Temperature range	-200°C to 1180°C
Time response	Bare wire: less than 1 millisecond Typical packaging: 2 to 3 seconds
Size constraints	.003" diameter

In addition to a wide temperature range capability, thermocouples are available in diameters down to .003" or about the size of a human hair.

Selection

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Environment

Consideration	Thermocouple
Vibration	Best choice for extreme conditions – shock or vibration
Ambient temperature	unaffected
Control system	unaffected
Distance to control system	Local transmitter often less expensive than lead wire – robust signal

Processes that have high vibration or mechanical shock are locations where thermocouples are a good choice. Their durability and high temperature capability allow them to survive conditions that quickly destroy other types of sensors.

Selection

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Cost

Consideration	Thermocouple
Initial cost	Low
Installation influences	- Lead wire is expensive - RFI/EMI considerations
Energy costs	Less accuracy means less control over energy usage
Replacement	Low cost but more frequent replacement is necessary

Extension grade lead wire can get expensive if it needs to be run a long distance. It's always a good idea to use shielded cable with the shield at the sensor end left open and the control end connected to a good ground. If running an extension more than a couple hundred feet the addition of a transmitter can insure a reliable and more accurate signal.

Typical Applications

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Thermocouples are commonly used for:

- Exhaust gas
- Injection molding
- Bearings
- Refinery
- Small aircraft engine temperature
- Chemical plants
- High temperature and/or fast response is required

Failure Modes

Thermocouples can drift and indicate incorrect temperature

- Physical makeup of the wire is altered and caused by:
  - Exposure to temperature extremes
  - Cold working the metal
  - Stress placed on the cable when installed
  - Vibration
  - Temperature gradients
  - Insulation resistance - decreases as the temperature increases
- In high-temperature applications using small gauge thermocouple wire the insulation can degrade to the point of forming a virtual junction
- High temperatures can release impurities and chemicals within the thermocouple wire insulation that diffuse into the thermocouple metal and change its characteristics. This alters the temperature vs. voltage relationship. Choose protective insulation intended for high-temperature operation to minimize these problems.

Failure Modes

Large errors can be caused by RFI/EMI noise and ground loops.

- Can be minimized by using an isolated or ungrounded junction
- Use shielded cable with the shield grounded at the instrument and open at the sensor end

Failure Modes

Preferential oxidation or "Green Rot"

- A phenomenon peculiar to nickel-based thermocouples, most often type K, when oxygen is limited. Oxygen reacts with the chromium in the conductors and changes to chromium oxide which creates a green scale. The result is a temperature measurement error.
- Preferential oxidation will not occur when there is an abundant supply or a total absence of oxygen.

One of the more common failure modes especially for type K thermocouples. Fortunately it is usually easily solved by changing to a different type thermocouple, more frequent replacement, or control the oxygen available to the junction.

The photo shows the tip of the sensor after cutting off the hot junction and the green stuff around the wires is the corrosion. This will change the thermoelectric characteristics and left unchecked will eat through the wires resulting in an open circuit.

Calibration

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Process conditions determine calibration frequency

- Track drift rate at each location
- Calibration is usually made by comparison to standard. The thermocouple may be removed from its installation and checked by comparison to a working standard in a hot block or bath.
- The working standard may be inserted in a test well near the thermocouple to make the calibration checks. Another method is to wait until the process has reached a constant temperature and make observations with the thermocouple being tested, then remove the thermocouple and insert a standard.
- Complete 5 cycles w/o shift then double the interval

Although it is not usually possible to obtain as high a precision by testing thermocouples in place as in laboratory tests, the results are far more accurate by being representative of the thermocouple behavior in actual use. Three standard thermocouples should be maintained. One is used as the working standard. The second is used for laboratory checks of the working standard. The third is used as a "referee" if the first two disagree.

Construction Types

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Mineral insulated cable – MgO compressed around conductors

MI cable as it is commonly called is the most prevalent type of construction and makes for a very durable and bendable sensor. High purity materials will ensure low drift and a longer life.

Construction Types

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Mineral insulated cable is available in many different sizes which allows for some unique solutions to difficult measurements. This one is .040” diameter and was coiled to improve flexibility that allowed insertion into a ½” tube with a compound bend in it.

Construction Types

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Tube and wire – metal tube housing insulated wires. Wires insulated with ceramic, fiberglass, or plastics.

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Thermocouple wire and MI cable is available in nearly every imaginable insulation material or metal alloy.

Construction Types

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Type R, S, and B thermocouples require the use of ceramic protection tubes. A typical sensor assembly as shown is installed into one, two or sometimes even three additional ceramic tubes.

Type R Thermocouple

Ceramic Thermowell

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Additional protection is required for the platinum alloy thermocouples. Protection from the process with the use of multiple ceramic tubes isolates the junction and wires from contamination insuring an accurate measurement.

Construction Types

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Ceramic thermowell

- Common materials are alumina, silicon carbide mullite, porcelain

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Ceramic materials are the choice for the platinum alloy thermocouples. One of the more durable although expensive materials, sintered silicon carbide, and goes by the trade name of Hexoloy® .

Summary

- Thermocouples are a simple device but have to be installed correctly to perform accurately
- Work well in applications where high temperature, durability, fast time response, or point contact is required
- Choose suitable construction type for the application for best accuracy and longest life
- Can be calibrated but in most cases it needs to be done in-situ

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