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RTD or Thermocouple: What's the Right Choice?

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Your Host and Presenter

Presenter
Bill Bergquist, Sr. Applications Engineer and RTDologist™

- 30 years experience in temperature measurement with RTDs and thermocouples in the aerospace, industrial, and laboratory markets.

Host
Jeff Wigen, National Sales Manager

- 24 years in sales and marketing of custom designed made-to-order products for the industrial and biotech markets.

Agenda

Thermocouple
- Basic Operation
- Types
- Temperature Range
- Performance

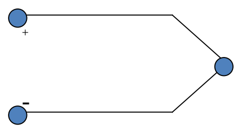
RTD
- Basic Operation
- Types
- Temperature Range
- Performance

Sensor selection
Typical applications
Questions

Thermocouple

Basic Operation

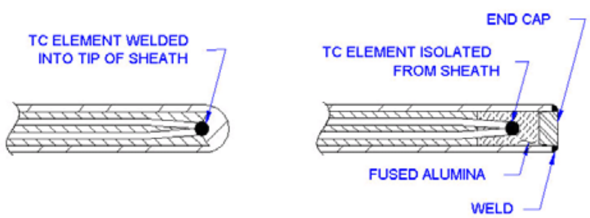
- TC made by connecting two dissimilar metals
  - When passed through a temperature gradient a small voltage is generated (5 to 6 mV @ 100°C)
- Voltage increases with temperature in predictable manner
- Require cold junction compensation – typically handled by the measurement electronics



Thermocouple

Types

- Junctions can be grounded, ungrounded or exposed



GROUNDED TIP DETAIL

UNGROUNDED TIP DETAIL

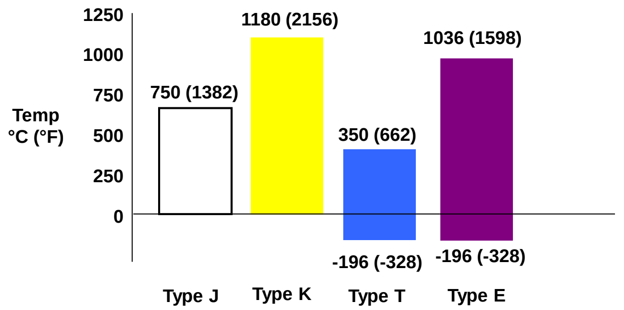
Thermocouple

Types

- Base metal - most common
  - Type T: Copper-Constantan Red/Blue
  - Type J: Iron-Constantan Red/White
  - Type E: Chromel-Constantan Red/Purple
  - Type K: Chromel-Alumel Red/Yellow

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

Temperature range



Performance

- Specifications
  - There are over 20 ASTM standards and IEC 60584 that specify thermocouple characteristics
  - Sheath material is typically 304 or 316 SST on type T, J, E and Inconel 600 for type K to handle the higher temperatures
    - Other sheath materials can be specified based on application
  - Larger wire is desirable for higher temperatures to minimize drift
  - Lead wires are color coded
  - Special or standard limits of error

Performance

- Accuracy - standard or special limits of error wire

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 -62.5°C error is 0.8% *** -200°C to -170°C error is 0.8%			

Basic Operation

- RTD = Resistance Temperature Detector or PRT (Platinum Resistance Thermometer)
- Resistor made from platinum, nickel, copper or other metals
- Most common material is platinum due to stability and linearity

Basic Operation

- How it works – electrical resistance changes very predictably with temperature changes. Temp goes up resistance goes up.
- Small current is sent through the resistor element and electrical resistance is measured
- Performance defined by IEC 60751 and ASTM E1137

Basic Operation

- Temperature coefficient
  - Also called the Temperature Coefficient of Resistance or alpha (α)
  - Units are ohms/ohm/°C
  - The average change in resistance per unit change in temperature between 0 and 100°C
  - $\alpha = R_{100} - R_0 / 100°C*R_0$
    - » R_0 = resistance at 0°C
    - » R_{100} = resistance at 100°C

RTD

Most common coefficients

- 0.00385 – ASTM E1137 or IEC 60751
- 0.003925 - SPRT, Secondary SPRT
- 0.003916 – JIS
- 0.003902 – Old U.S. standard – no longer used

- Must match your instrument to the proper temperature coefficient of your sensor

RTD

Coefficient example

- A temperature is being measured with a sensor having a temperature coefficient of .003916 (JIS) but due to a sensor failure it was replaced with a sensor having a temperature coefficient of .00385 (IEC standard).
- If the transmitter/controller is not recalibrated, at 100°C it will read 1.7°C low.

Interchangeability

Interchangeability (largest component of sensor accuracy)

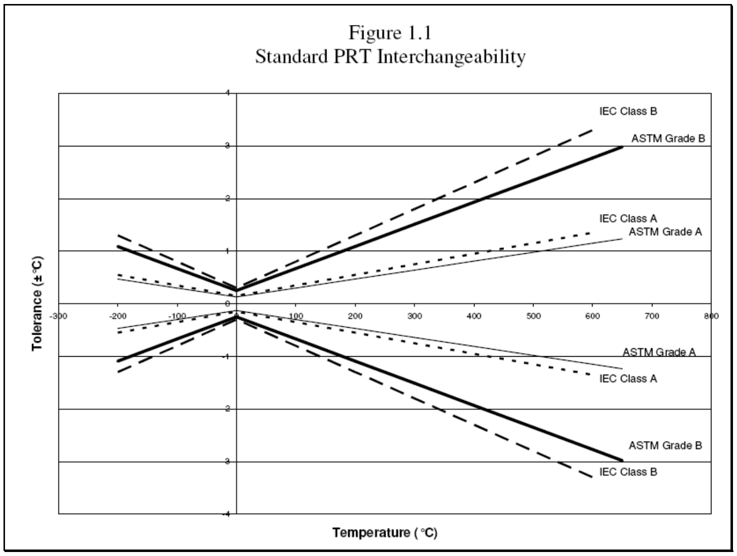
- Refers to the "closeness of agreement" in the resistance vs. temperature (R vs. T) relationship of a PRT to a pre-defined nominal R vs. T relationship.

Table 1.1
Standard PRT Interchangeability Equations

Standard	Tolerance Nomenclature	Defining Equation[1]
ASTM E1137	Grade A	± [.13 + 0.0017 | t |]
ASTM E1137	Grade B	± [.25 + 0.0042 | t |]
IEC 60751	Class A	± [.15 + 0.002 | t |]
IEC 60751	Class B	± [.3 + 0.005 | t |]

Note 1: | t | = the value of temperature in °C without regard to sign

Two standards are in use that defines the R vs. T relationship and within each there are two classes or grades of interchangeability.



This graph shows the relationship between temperature and the interchangeability tolerance for each of the standards and classes. The ASTM Grade A has the tightest tolerance.

RTD's are manufactured to be100 ohms at 0°C. The two standards provide a common target for them to hit and the acceptable tolerances. As the temperature diverges from 0°C the tolerances increase.

RTD

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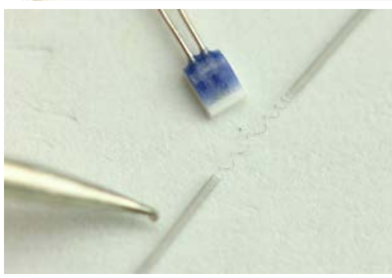
Types

- Elements
  - Wire wound
    - External wound
    - Coil
  - Thin Film
- Single or Dual



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RTD

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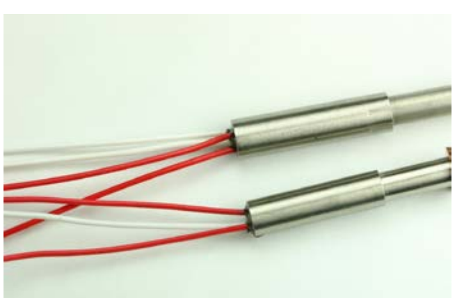
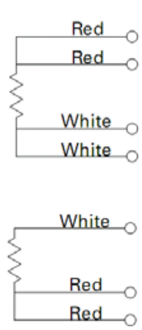
Wires

- 2, 3, and 4 Wire





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Lead Wire Compensation

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2 wire connection adds lead resistance in series with PRT element.

3 wire connection relies on all 3 leads having equal resistance.

- +0.16°F per 100 ft. of 18 AWG cable (worst case)

4 wire connection eliminates lead wire error

Lead wires used to connect the sensor to a process control instrument can cause a measurement error. Two and three wire circuits have the largest errors and the 4 wire will nearly eliminate the error.

Lead Wire Compensation

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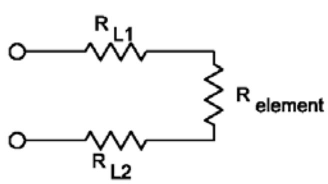

$$R_{measured} = R_{L1} + R_{element} + R_{L2}$$

Two wire circuits simply add the lead resistance to the sensing element resulting in very large errors.

Lead Wire Compensation

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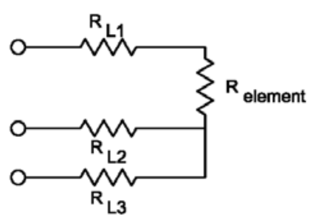

$$R_{measured} = R_{L1} + R_{element} + R_{L2} - [R_{L2} + R_{L3}]$$

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

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

A three wire circuit will add no error if each of the three legs have the exact same resistance. Unfortunately, in the real world there is a difference and that causes an error.

Lead Wire Compensation

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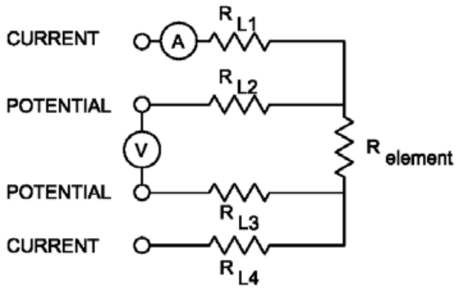

$$R_{measured} = \frac{V}{A}$$

The current potential method or 4 wire circuit is the most accurate and has little or no error associated with it.

RTD

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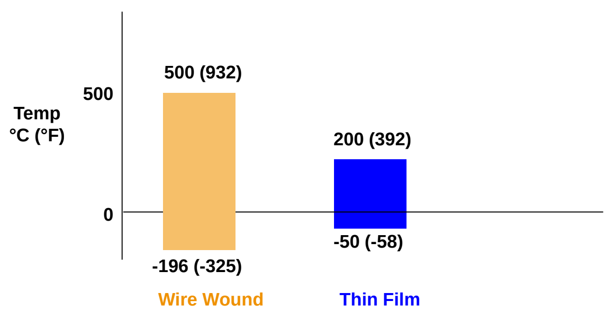
Temperature Range



RTD

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Performance

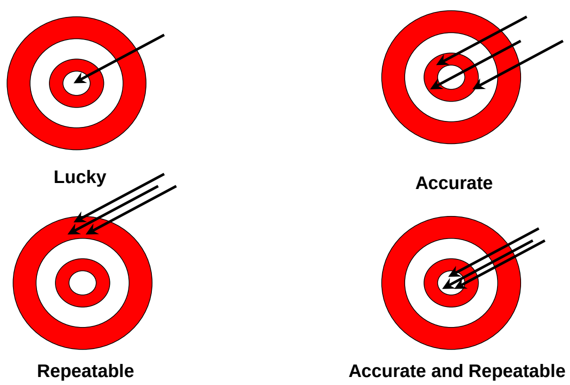
	Wire Wound	Thin Film
Element Resistance	100 ohms	100, 1000 ohms
Accuracy 0°C/200°C	± 0.13°C/0.5°C	± 0.26°C/1.0°C
Repeatability	0.1°C	0.1°C
Time Response	4.0 Sec.	6.0 Sec.
Temp. Range	-200 to 500°C	-50 to 200°C
Vibration	15 g's	20 g's
Stability	.1°C	.5°C

Sensor Selection

RTD or Thermocouple?

- Performance
- Process characteristics/needs
- Environment
- Cost considerations

Accuracy and Repeatability



An analogy for accuracy and repeatability is illustrated with arrows shot at a target. Hitting the bull's-eye time after time represents good accuracy and repeatability.

Sensor Selection

Performance

Consideration	Thermocouple	RTD
Accuracy at 32°F	Standard limits: ± 4°F* Special limits: ± 2°F*	Grade B: ± 0.54°F Grade A: ± 0.27°F
Calibration	Limited to in-situ calibration	- Easily recalibrated for longer service life and traceability - Matching transmitter improves performance
Stability	Dependent on wire homogeneity and process conditions	Average drift is ± 0.06°C after 1000 hours at 400°C.
Repeatability	Highly dependent on process characteristics	Less than ± 0.04% change in ice point resistance after 10 cycles -200 to 500°C.

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

Sensor Selection

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Process Characteristics

Consideration	Thermocouple	RTD
Temperature range	-200°C to 1180°C	-200°C to 500°C
Time response	Bare wire: less than 1 millisecond Typical packaging: 2 to 3 seconds	2.5 seconds Typical packaging 4 to 6 seconds
Size constraints	Can be less than 1/8" in diameter	Smallest diameter 1/8", typically 3/16" or 1/4"

Sensor Selection

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Environment

Consideration	Thermocouple	RTD
Vibration	Best choice for extreme conditions – shock or vibration	Limited to 30 g's at 5 to 350 Hz
Ambient temperature	Either	Either
Control system	Either	Either
Distance to control system	Local transmitter often less expensive than lead wire – robust signal	Add a local transmitter if over 300 ft.

Sensor Selection

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Cost

Consideration	Thermocouple	RTD
Initial cost	Low	Medium to high
Installation influences	- Lead wire is expensive - RFI/EMI considerations	-Uses standard 18 AWG instrument wire -Less RFI/EMI interference
Energy costs	Less accuracy means less control over energy usage	Accurate control of energy consumption = $$ savings
Replacement	Low cost but more frequent replacement is necessary	- Can last many years - Lowest life cycle cost

Typical Applications

Thermocouple
- Exhaust gas
- Injection molding
- Bearings
- Refinery

RTD
- Pharmaceuticals
- Fuel custody transfer
- Chemical
- Tire /rubber

Quick guide

Situation	Thermocouple	Wire Wound RTD	Thin Film RTD
Accuracy/Stability		X	
Low Temp (-50 to 200°C)		X	X
High Temp (-200 to 500°C)		X	
Higher Temp (up to 1260°C)	X		
Time Response (< 6 sec.)	X	X	
Long-term Stability		X	
High Vibration (g level)	X		X
Extra High Vibration, Shock	X		X
Critical Temp. Application		X	

Summary

Every application is different

Start with an RTD
- Accurate
- Stable
- Repeatable
- Easily calibrated

If process conditions exclude usage then look at using a thermocouple
- Durable
- High temperature capability