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Lecture basic principles electric temperature measurement

Instrumentatie & Analyse Dagen 2017

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Electrical Thermometers

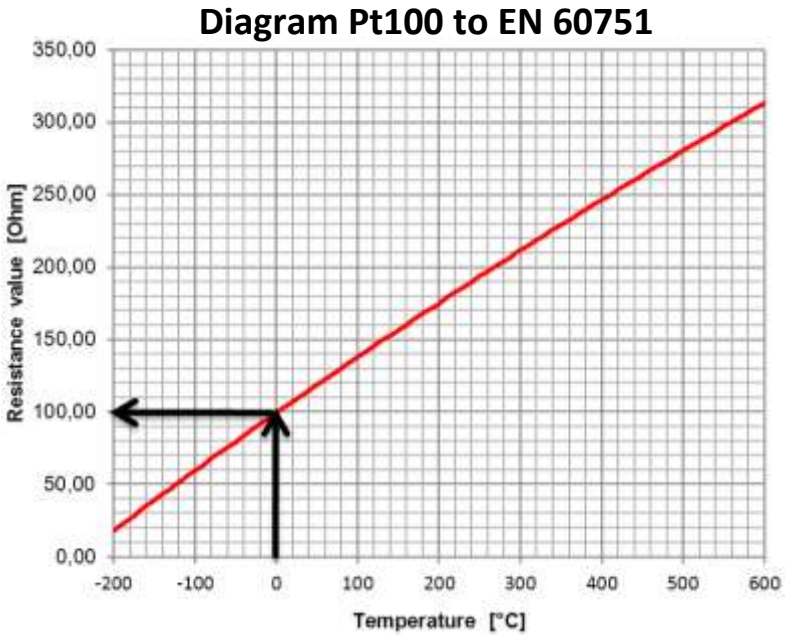
Designs of industrial electrical thermometers

Standard-Design with connection Head

- Connection head
- Measuring insert
- Neck tube
- Thermowell / protection tube

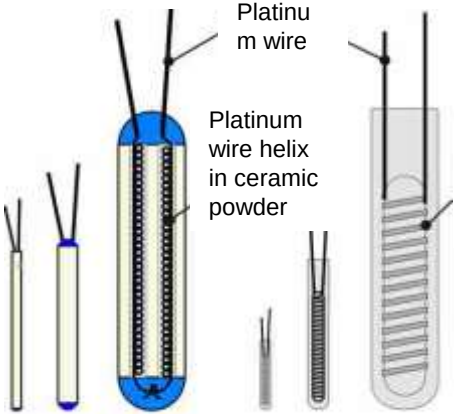
Electrical Thermometers

RTD: Characteristic curve



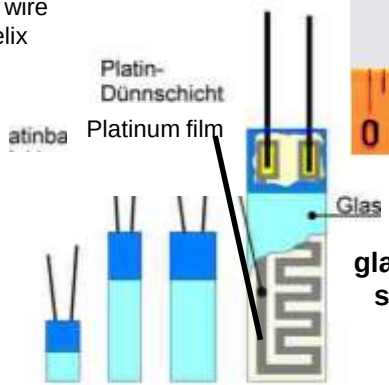
Electrical Thermometers

RTD: Sensor
2 principles and 3 versions



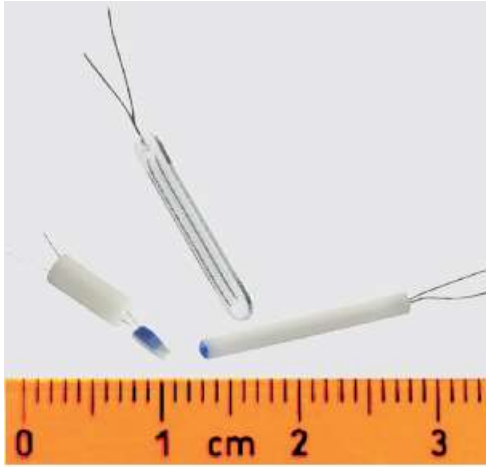
ceramic **glass sensor**

wire wound



glass

thin film sensor



Electrical Thermometers

RTD: Thinfilm sensor

PROS

- High vibration resistance
- Good price/benefit ratio
- Small size

CONS

- Limited temperature range: -30...+300 ºC (class A)
- Not fully accepted by chemical industry

Electrical Thermometers

RTD: Ceramic sensor

PROS

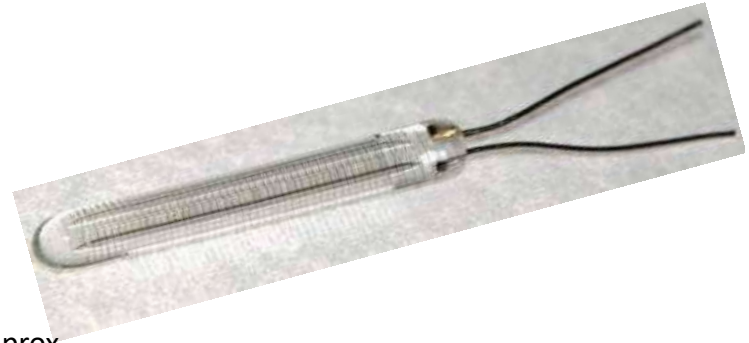
- Full temperature range -200…+600 ºC (class B)
- Accepted by all customers (including Chemical Industry)

CONS

- Limited vibration resistance
- Medium price

Electrical Thermometers

RTD: Glass sensor



PROS

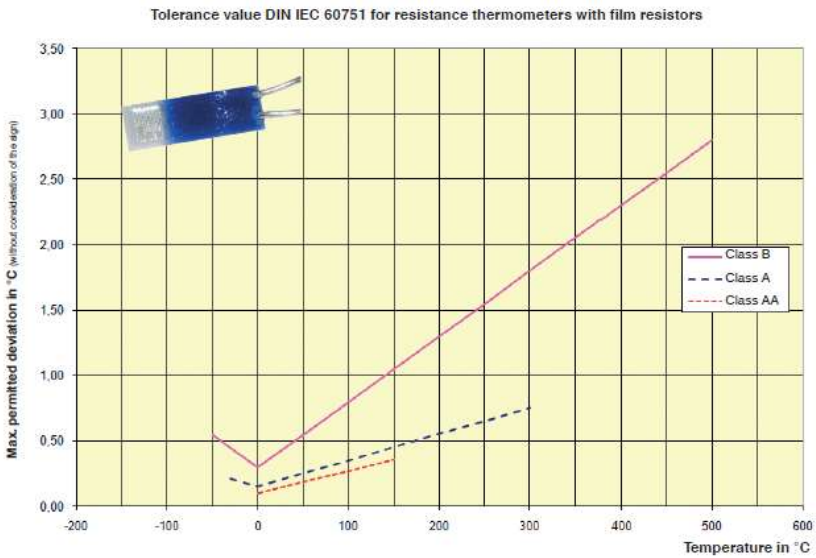
- High vibration resistance
- Accepted by all customers

CONS

- The upper temperature is limited to approx. +400 ºC because of electrical conductivity of the glass bulb above this temperature
- High price

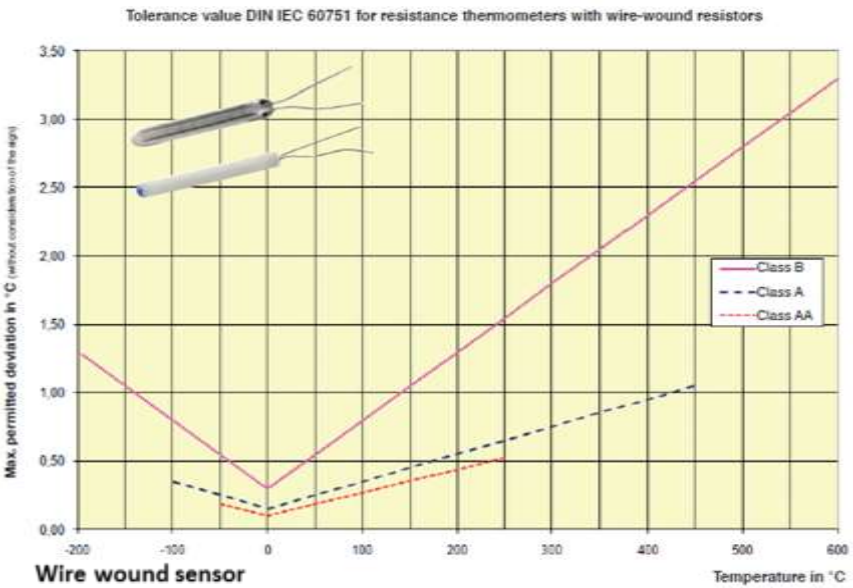
Electrical Thermometers

RTD: Temperature ranges and tolerance classes



Thinfilm sensor

- Class B -50 °C ... + 500 °C ± (0.30 + 0.0050 | t |)
- Class A -30 °C ... + 300 °C ± (0.15 + 0.0020 | t |)
- Class AA 0 °C ... + 150 °C ± (0.10 + 0.0017 | t |)



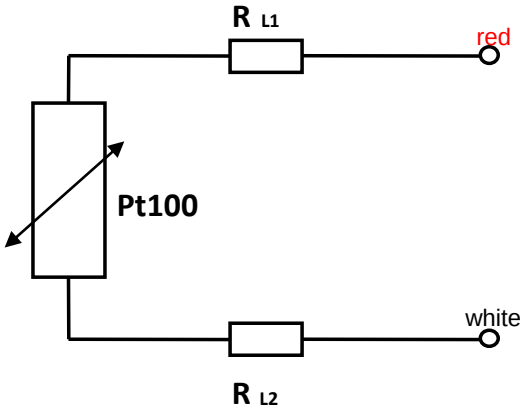
Wire wound sensor

- Class B -200 °C ... + 600 °C ± (0.30 + 0.0050 | t |)
- Class A -100 °C ... + 450 °C ± (0.15 + 0.0020 | t |)
- Class AA - 50 °C ... + 250 °C ± (0.10 + 0.0017 | t |)

Electrical Thermometers

RTD: Wiring configuration

2-wire-circuit



Easy and cheap

- For short wire lengths only
- Measuring error because of wire resistance

Sample:

Length of wire: 100m
cross section: 0,5mm² (40 Ohm/1000 m)

$$2 * R_{line} = 2 * 100\ m * \frac{40\ Ohm}{1000\ m} = 8\ Ohm$$

This leads to an error of approx. **21 °C (!)**

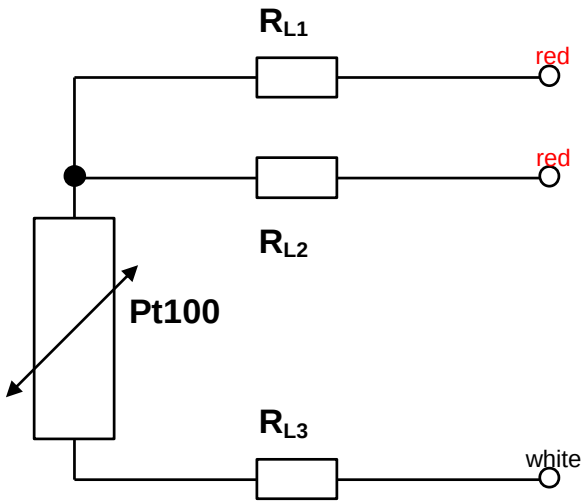
(Widerstand in Ω)

	0	1	2	3	4	5	6	7	8	9	10
-10	96,086	96,478	96,870	97,261	97,653	98,044	98,436	98,827	99,218	99,609	100,000
0	100,000	100,391	100,781	101,172	101,562	101,953	102,343	102,733	103,123	103,513	103,903
10	103,903	104,292	104,682	105,071	105,460	105,849	106,238	106,627	107,016	107,405	107,794
20	107,794	108,182	108,570	108,959	109,347	109,735	110,123	110,510	110,898	111,286	111,673

Electrical Thermometers

RTD: Wiring configuration

3-wire-circuit

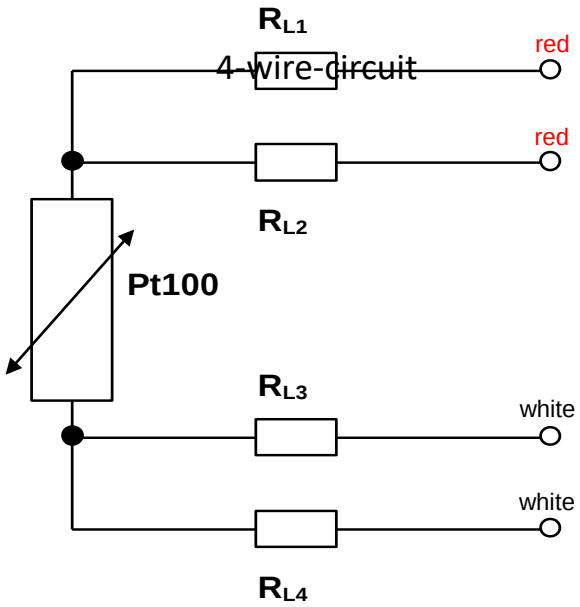


Good cost/benefit ratio

- No measuring error if the resistances of all 3 wires are identically
- Recommended wire length up to 30 meter
- Industrial-Standard wiring of RTD's
- Suitable for standard transmitter configuration

Electrical Thermometers

RTD: Wiring configuration

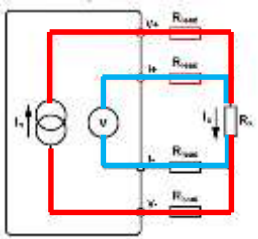


No influence of wire resistance

- Wire resistance is fully compensated
- Recommended for wire length over 100 meter

Applications

- Calibration lab and high accuracy measurement
- For accuracy classes A or AA
- For SIL - applications



1. *A **constant current regarding to the sensor** produces a voltage drop at the sensor Pt100*
   (The line resistance does not influence the current)

2. *At the **second path** the voltage drop caused before can be measured. Due to the fact that we measure with high-impedance, the line resistance is not relevant anymore*

Result: *Sensor value* R_{Pt100} = U / I

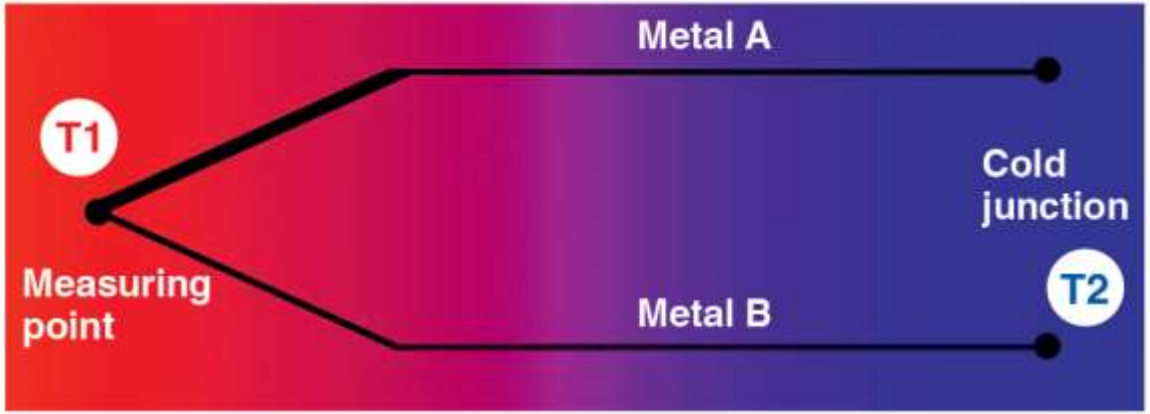
Electrical Thermometers

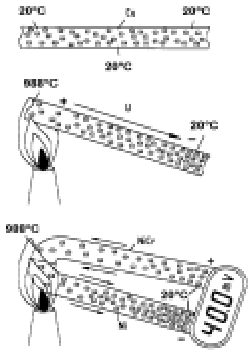
Thermocouple: Basics

The thermo-electric effect (Seebeck effect)

A thermocouple never measures an absolute temperature
It measures the difference between:

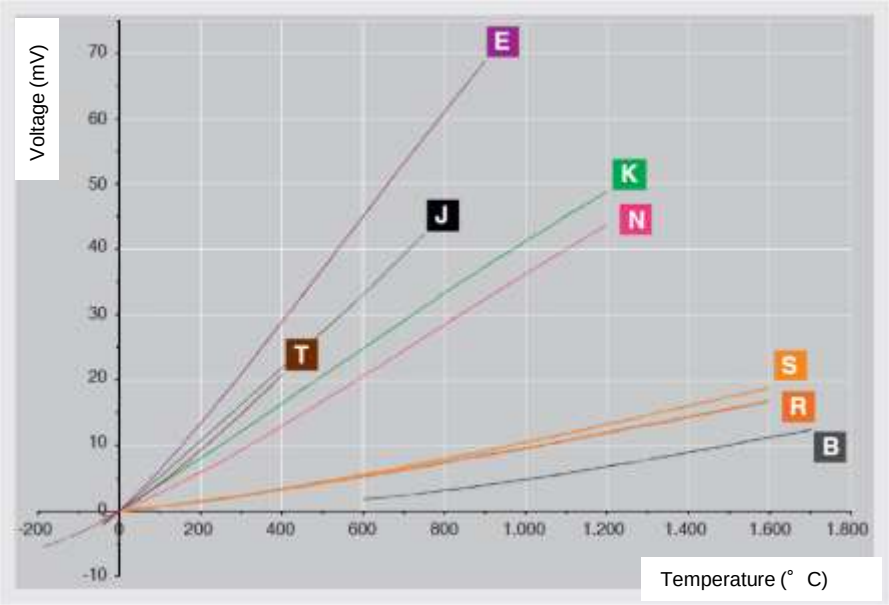
- **T1**: the measuring point (hot junction) and
- **T2**: the basis point (cold junction)





Electrical Thermometers

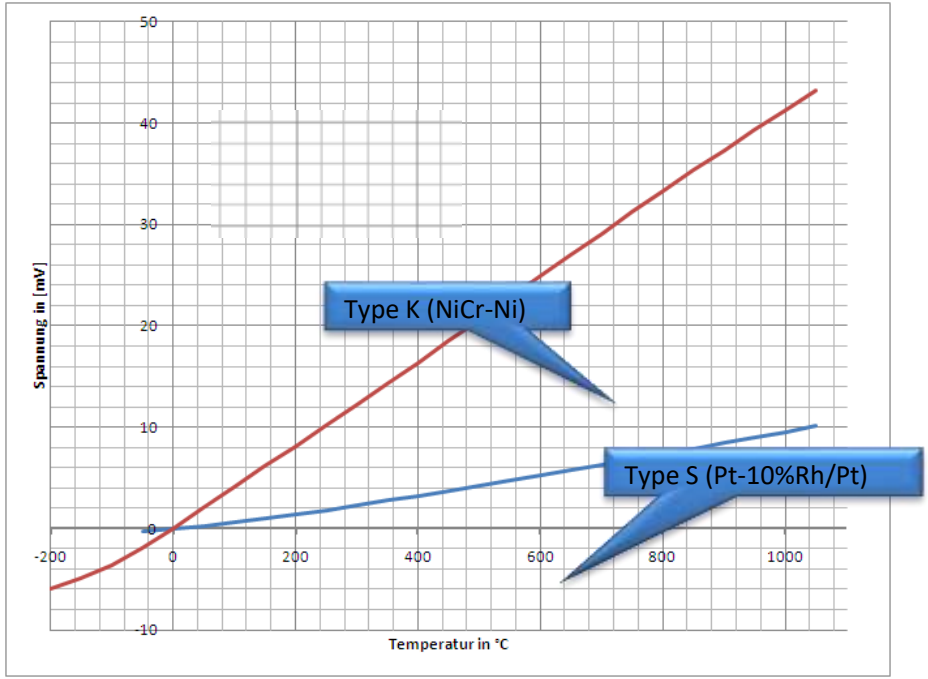
Thermocouple: Characteristic curve



- Each thermocouple has a different characteristic curve
- The curves are not linear

Electrical Thermometers

Thermocouple: Characteristic curve



- Difference between precious and non-precious thermocouples

Electrical Thermometers

Thermocouple: Types

Model	Thermocouple	Tolerance value per	Class	Temperature range	Tolerance value
K N	NiCr-Ni NiCrSi-NiSi	IEC 60584 part 2	1	-40 ... +1000 °C	±1.5 °C or 0.0040 · | t | [1) 2)]
			2	-40 ... +1200 °C	±2.5 °C or 0.0075 · | t |
		ASTM 14.03 E230	Special	0 ... +1260 °C	±1.1 °C or ±0.4 %
			Standard	0 ... +1260 °C	±2.2 °C or ±0.75 %
J	Fe-CuNi	IEC 60584 part 2	1	-40 ... +750 °C	±1.5 °C or 0.0040 · | t |
			2	-40 ... +750 °C	±2.5 °C or 0.0075 · | t |
		ASTM 14.03 E230	Special	0 ... +760 °C	±1.1 °C or ±0.4 %
			Standard	0 ... +760 °C	±2.2 °C or ±0.75 %
E	NiCr-CuNi	IEC 60584 part 2	1	-40 ... +800 °C	±1.5 °C or 0.0040 · | t |
			2	-40 ... +900 °C	±2.5 °C or 0.0075 · | t |
		ASTM 14.03 E230	Special	0 ... +870 °C	±1.0 °C or ±0.4 %
			Standard	0 ... +870 °C	±1.7 °C or ±0.5 %
T	Cu-CuNi	IEC 60584 part 2	1	-40 ... +350 °C	±0.5 °C or 0.0040 · | t |
			2	-40 ... +350 °C	±1.0 °C or 0.0075 · | t |
			3	-200 ... +40 °C	±1.0 °C or 0.015 · | t |
		ASTM 14.03 E230	Special	0 ... +370 °C	±0.5 °C or ±0.4 %
			Standard	-200 ... 0 °C	±1.0 °C or ±1.5 %
			Standard	0 ... +370 °C	±1.0 °C or ±0.75 %
R S	Pt13%Rh-Pt Pt10%Rh-Pt	IEC 60584 part 2	1	0 ... +1600 °C	±1.0 °C or ±[1 + 0.003 (t - 1100)] °C
			2	0 ... +1600 °C	±1.5 °C or ±0.0025 · | t |
		ASTM 14.03 E230	Special	0 ... +1480 °C	±0.6 °C or ±0.1 %
			Standard	0 ... +1480 °C	±1.5 °C or ±0.25 %
B	Pt30%Rh-Pt6%Rh	IEC 60584 part 2	2	+600 ... +1700 °C	±0.0025 · | t |
			3	+600 ... +1700 °C	±4.0 °C or ±0.005 · | t |
		ASTM 14.03 E230	Special	-	-
			Standard	+870 ... +1700 °C	±0.5 %

1) \|t\| is the value of the temperature in °C without consideration of the sign
2) The greater value applies

Electrical Thermometers

Thermocouple: Comparison

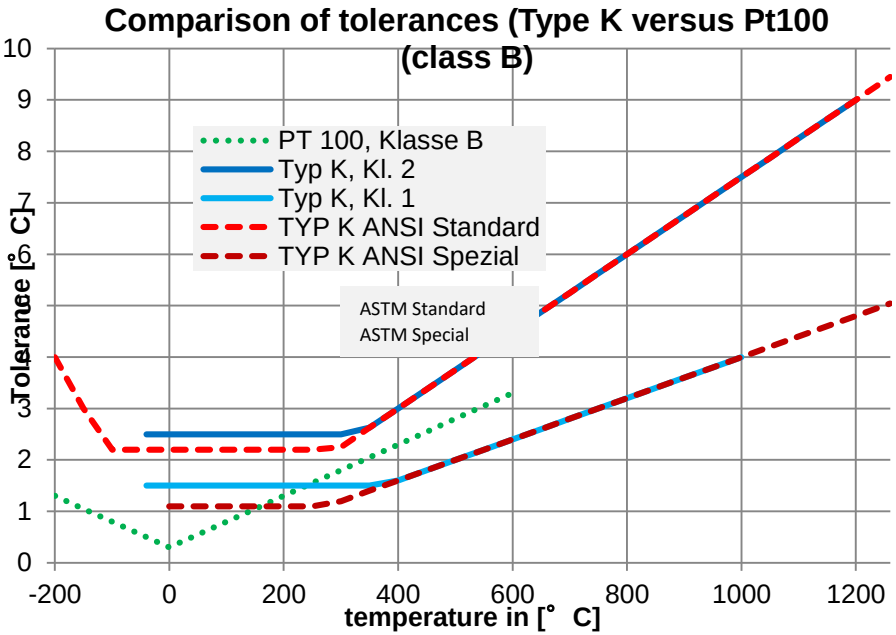
EN 60584-2 / IEC 60584-2

- Class1
- Class 2

ASTM 14.03 E230

North American Standard

- Standard
- Special



Electrical Thermometers

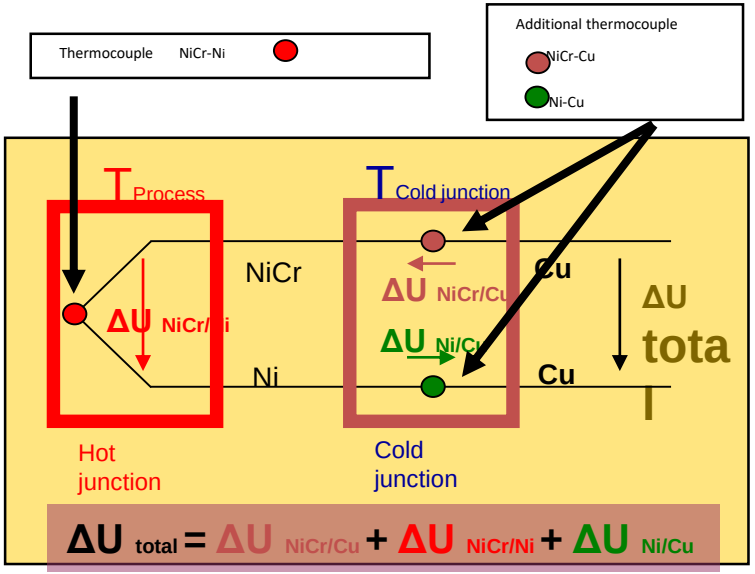
Thermocouple: Wires and cables

Using the wrong cables will lead to errors

Example:

If a standard **copper** cable is beeing used to transmit the signal of the thermocouple to the transmitter or controller, the two new (undefined) thermocouples will cause a measuring error.

➔ Because of this reason a special kind of cable is need to transmit the thermocouple signal (thermo wire and compensation wire).



Electrical Thermometers

Thermocouple: Wires and cables

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Thermo wire:

Are made of **identical** material as the thermocouple

+ accuracy
- cost

Compensating cable

Are made of **similar** material as the original thermocouple

+ cost
- accuracy (class 2 only)
- limited temperature range

Lead wire insulation

- **Material**: PVC, silicon, Teflon, fibreglass
- **Armour**: with or without

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Thermocouple: Wires and cables

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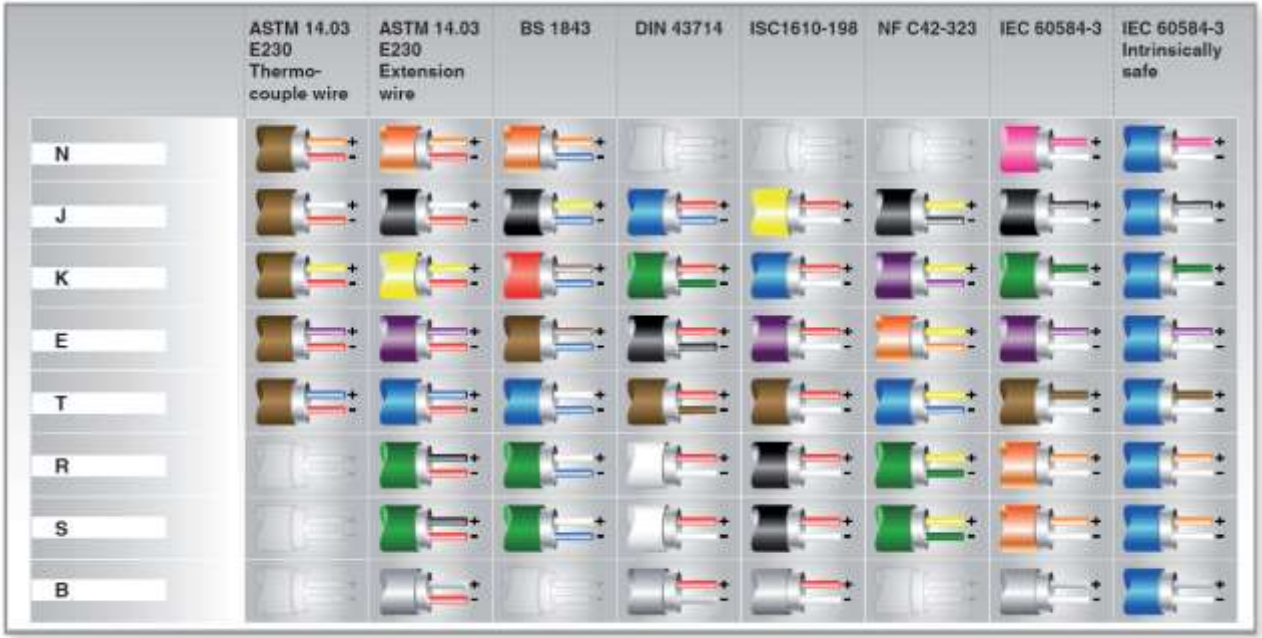
Colour codes



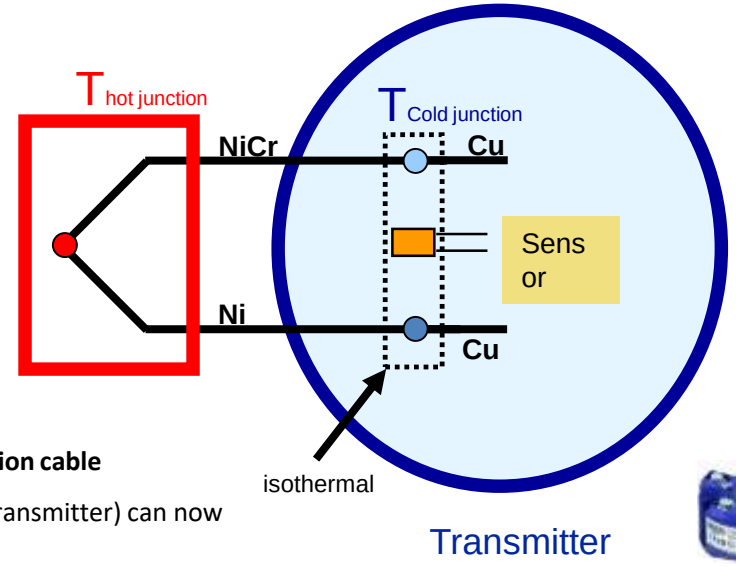
Thermocouple: Wires and cables

Temperature compensation with a transmitter

Using an internal temperature sensor, the transmitter measures the temperature of its terminals.

The Transmitter calculates the cold junction temperature to 0 ºC.

The temperature difference between cold junction and hot junction shows the real temperature of the hot junction now.



Result:

No need for special thermo-wire or compensation cable

The signal (transformed from mV to mA in the transmitter) can now being transmitted via copper wires.

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Electrical Thermometers

Components – MI-cable

MI-cable advantages

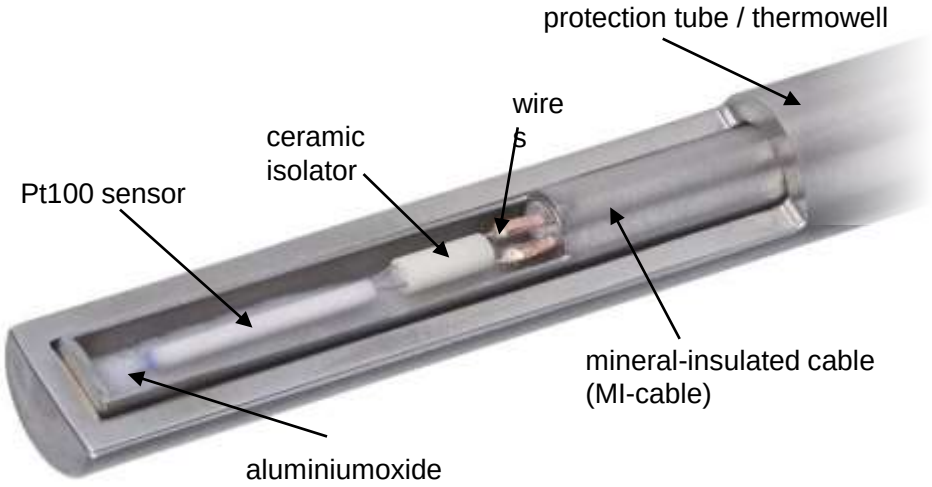
- High variety of dimensions and materials
- Flexible
- Highly compressed MgO (Al_2O_3)-Powder
- Suitable for Ex-applications

MI-cable disadvantages

- Hygroscopic
- Nothing else

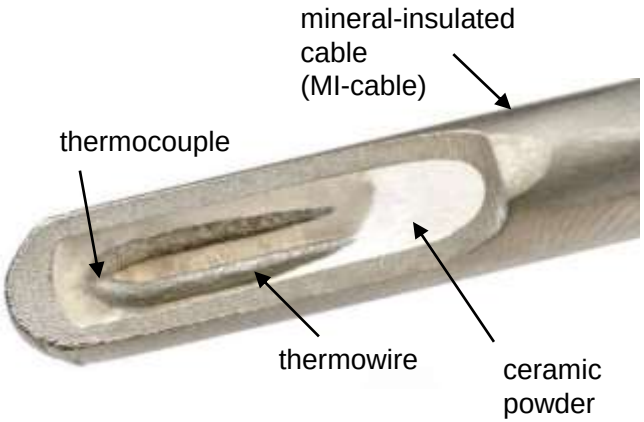
Electrical Thermometers

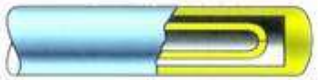
RTD: Inside view



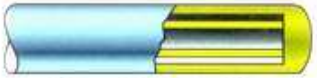
Electrical Thermometers

Thermocouple: Inside view





Ungrounded Junction

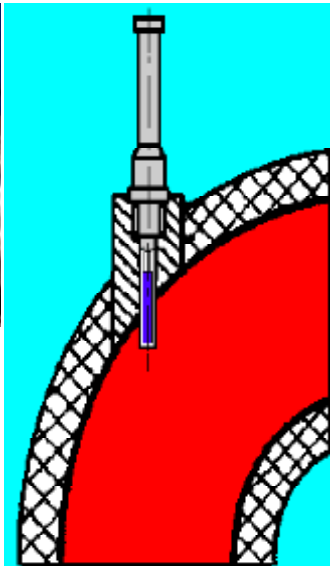


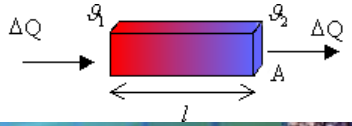
Grounded Junction

What does it mean:
Temperature measurement with mechanical contact?

- The establishing of a mechanical or thermal contact needs an adequate heat conductance between the measured object (solid, fluid, liquid, gas) and the sensor

- The measurement accuracy of the system can be disturbed via e.g. not balanced heat conductance, air flow, or heat abstraction of the sensor.

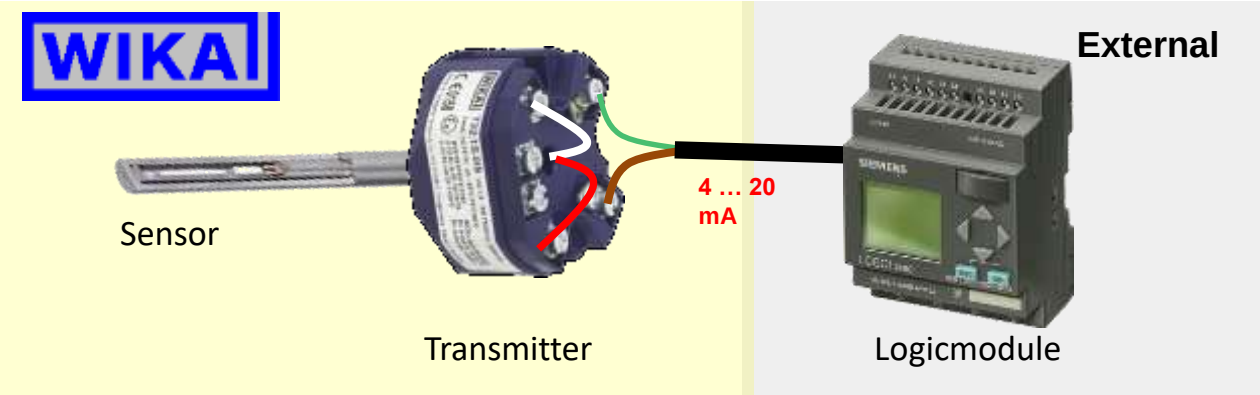




Temperature-Measurement caused by temperature radiation (pyrometer) is also possible, but not discussed within this training

What actually does a Temperature transmitter do?

- The transmitter forms a analogue signal (signal from the sensor) in a **standardized** analogue or digital output signal
- **Standardized** output signals used in the instrumentation technology are:
  Analogue: 4 … 20 mA (incl. HART®) / 0…10 V
  Digital: fieldbus protocols like Foundation™ Fieldbus or PROFIBUS®



Why do customers use temperature transmitter? Why don't they use the logicmodule directly?

- **The measured signals are very low and very fragile** according to disturbances high electromagnetic disturbances on the sensor line causes problems regarding to the measurement with the logicmodule

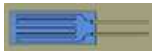
- **Long distances between sensor and transmitter**
  - for Resistance Measurement (Pt100):
    big failure of the wire resistance → connection has big influences at the measurement result → use a 3-wire or even better a 4-wire connection
  - for Thermocouple:
    The wire-material must be the same as the used Thermocouple (or a special material) → very expensive

- **The sensor could be placed in a hazardous protection area**
  The energy to use the sensor must be limited,
  and the sensor must not be warmed up either.
  → It is not possible to use a logicmodule anymore for this kind of application

Which general tasks face the temperature transmitter in the field?

- Faithfully measurement of the very low signals of the different sensors (Pt100: 160µV / thermocouple: 60µV)

  - For Pt100 sensors is valid:
    measurements possible with 2-/3-/4-wire connections
  - For thermocouple is valid:
    It is necessary to do a compensation during the measurement

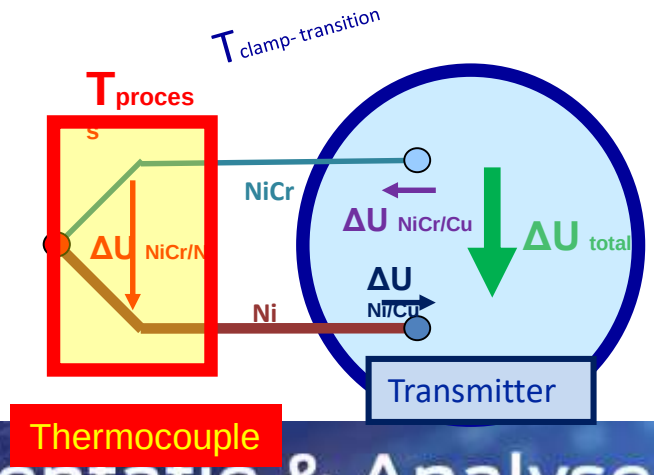


- Often in the field; technical tasks:
  - High electromagnetic disturbances on the sensor line
  - Long distances between sensor and transmitter

- Tasks from our customers:
  - Configuration of the transmitter (variety of potential sensors)
  - Hazardous area protection
  - Signalization in case of an error (e.g. sensor burnout)

How is a Thermocouple connected to a Temperature Transmitter?

- 2-wire connection:
  Wire 1 (Metall_1) and **wire 2 (Metall_2)**
- **Wire 1 (Metall_1)** at the one **clamp (Material_clamp)** as well as **wire 2 (Metall_2)** at the other **clamp (Material_clamp)** produces further ***unwanted Thermocouples*** and therefore additional (unwanted) voltages.



What measures the Transmitter?

1. *The Thermo-Voltage:*

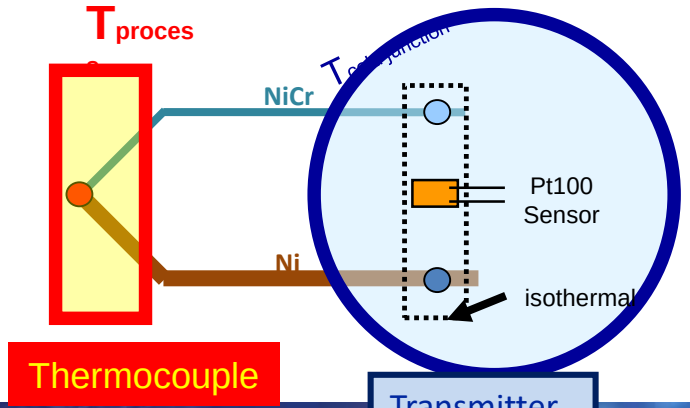
ΔUtotal = ΔU NiCr/Cu + ΔU NiCr/Ni + ΔU Ni/Cu

Result: A highly, additional error depending on the used Thermocouple-material

$T_{proces\,s} + T_{Unwanted}$

How can we eliminate the unwanted Thermocouple-voltages?

- 2-wire connection:
  Wire 1 (Metall_1) and **wire 2 (Metall_2)**
- **Wire 1 (Metall_1)** at the one **clamp (Material_clamp)** as well as **wire 2 (Metall_2)** at the other **clamp (Material_clamp)** produces further ***unwanted Thermocouples*** and therefore additional (unwanted) voltages. The measurement of the integrated Pt100 (placed near by the **clamps**) and calculation of these values eliminates this disturbance voltages.



What measures the Transmitter?

1. *The Thermo-Voltage:*
2. *The internal Pt100 Sensor. The Transmitter calculates the measured values*

$\Delta U_{total} = \Delta U_{NiCr/Cu} + \Delta U_{NiCr/Ni} + \Delta U_{Ni/Cu}$

Result: $T_{process}$

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Thank you very much for your attention!