Temperature sensors

by
Dr. Sotiris Omirou
AMEM 211

Temperature sensors using electrical effects

- a. Resistive Thermometers Detectors or RTD
- b. Thermistors
- c. Thermocouple

- Very convenient methods because they furnish a signal that is easily detected, amplified, or used for control purposes.
- Quite accurate methods
Resistive Thermometers - RTD

**How it works:**
- Utilizes the fact that resistance of a metal changes with temperature. Thus the temperature is indicated through the measurement of the change in resistance of the element.

**Make up:**
- Traditionally made up of platinum, nickel, tungsten or copper wound around an insulator.

**Temperature range:**
- From about -196°C to 482°C.

---

Resistive Thermometers - RTD

Metals such as

- **Platinum**
- **Copper**
- **Tungsten**
- **Nickel**

present small increases in resistance as the temperature rises. They have **positive** temperature coefficient of resistance.
Resistive Thermometers Detectors - RTD

- typical devices use platinum wire (such a device is called a **platinum resistance thermometers** or **PRT**)

  ![A typical PRT element](image)

RTD - Advantages and Disadvantages

- **Advantages:**
  - Stable
  - Very accurate
  - Change in resistance is linear

- **Disadvantages:**
  - Expensive
  - Current source required
  - Small change in resistance
  - Self heating
### Resistive Thermometers Detectors - RTD

\[ R_t = R_0 \left[ 1 + \alpha (\theta_t - \theta_0) \right] \]

where,

\[ \alpha = \text{temperature coefficient of resistance } \text{^0C}^{-1} \]

\[ R_0 = \text{resistance in } \Omega \text{ at the reference temperature } \theta_0 = 0^0 \text{C} \]

### Exercise 13

If the resistance of a platinum resistance thermometer is 100 Ω at 0^0 C,

Calculate:
- the resistance at 60^0 C if \( \alpha = 0.00392 \text{^0C}^{-1} \)
**Exercise 13**

**Solution:**

\[ R_t = R_0 \left[ 1 + \alpha (\theta_t - \theta_0) \right] \]

\[ = 100 \, \Omega \times [1 + 0.00392 \times 60] \]

\[ = 123.5 \, \Omega \]

**Exercise 14**

Consider a platinum resistance thermometer connected as one arm of the wheatstone bridge, as shown in the figure. The fixed resistances in the circuit are 200 Ω each, and the input voltage \( V_i \) is 10 volts. At 0 °C the circuit is balanced and at this temperature the thermometer has a resistance of 200 Ω.

If the temperature coefficient of resistance of platinum \( \alpha \) is 0.004 °C\(^{-1}\), determine the change in output voltage for a 1 °C change in temperature.
EXERCISE 14

1. **Data:**
   
   \[ V_i = 10 \text{ Volts} \]
   
   \[ R_0 = 200 \ \Omega \]
   
   \[ \alpha = 0.004 \degree \text{C}^{-1} \]
   
   \[ t = 1 \degree \text{C} \]

2. **Asked:**
   
   Change in output voltage \( V_0 \)

3. **Solution:**
   
   \[ R_1 = R_0 (1 + \alpha t) \]
   
   \[ R_1 = 200 \times [1 + (0.004 \times 1)] = 200 \times 1.004 \]
   
   \[ R_1 = 200.8 \ \Omega \]

   \[ \Delta R = R_1 - R_0 = 0.8 \ \Omega \]

   \[ \Delta V_0 = V_i \left( \frac{\Delta R}{R_1 + R_0} \right) = \]

   \[ = 10 \left( \frac{0.8}{200 + 200} \right) = 10 \times 0.002 = 0.02V \]

   Thus, for each degree change in temperature, there is a 20mV change in the output voltage.
Thermistors

- **How it works:**
  - Like the RTD a thermistor uses the fact that resistance of a metal changes with temperature.

- **Make up:**
  - Generally made up of semiconductor materials

- **Temperature Range:**
  - About -45°C - 150°C

Thermistors

Use oxides of

- Manganese
- Cobalt
- Chromium
- Nichel

present large changes in resistance with temperature variation. They have **negative** temperature coefficient of resistance
Thermistors

- sensitive but highly non-linear

A typical disc thermistor

A threaded thermistor

Thermistor
Advantages and Disadvantages

Advantages:
- Very sensitive (has the largest output change from input temperature)
- Quick response
- More accurate than RTD

Disadvantages:
- Output is a non-linear function
- Limited temperature range.
- Require a current source
- Self heating
- Fragile
Thermocouples

- **How it works:**
  - Made up of two different metals joined at one end to produce a small voltage at a given temperature.

- **Make up:**
  - Made up of two different metals.
  - Ex: A type J is made up of Iron and Constantan.

- **Temperature Range**
  - Type J: -40°C to 750°C

A few Thermocouples

Thermocouples

**Seebeck Effect**

*When a pair of dissimilar metals are joined at one end, and there is a temperature difference between the joined ends and the open ends, thermal emf is generated, which can be measured in the open ends. As $T_1$ increases, so does $V_{\text{OUT}}$.*

This forms the basis of thermocouples.

*The junction is placed in the process, the other end is the reference junction.*
Thermocouple
Advantages and Disadvantages

- **Advantages:**
  - Self Powered (does not require a current or voltage source)
  - Rugged
  - Inexpensive
  - Simple

- **Disadvantages:**
  - Extremely Low Voltage output (mV)
  - Not very stable

Thermocouples are among the easiest temperature sensors to use and obtain and are widely used in science and industry.

Thermocouples are the most common temperature sensing device. They can be made in very tough designs, they are very simple in operation and measure temperature at a point. Over different types they cover from -250°C to +2500°C.

Accurate temperature measurements can be made with thermocouples sensors at low cost with shop-built probes and ordinary low-level voltmeters.
More about Thermocouples

**Construction**

A thermocouple construction consists of two conductors, welded together at the measuring point and insulated from each other along the length. It will usually have an outer protection sheath.

![Diagram of thermocouple construction](image)

- Measuring Junction
- Sheath
- Conductors
- Insulator

More about Thermocouples

**Thermocouple Materials**

The three most common thermocouple materials for moderate temperatures are Iron-Constantan (Type J), Copper-Constantan (Type T), and Chromel-Alumel (Type K).

1) The first element of the pair is the positive element.
2) The negative wire is color coded red.

All three types (J, K, and T) are available as insulated duplexed pairs from 0.03 mm diameter on up. For accuracy, and minimum system disturbance, the smaller the wire the better, but wire smaller than 0.1 mm diameter is very fragile.
Standard Thermocouple Types

**Iron-Constantan:**
Type J
- Color coded white and red
- Generates about 50 μV/°C
- −40 to +750 °C

**Chromel-Alumel:**
Type K
- Color coded yellow and red
- Generates about 40 μV/°C
- −200 °C to +1350 °C

**Copper-Constantan:**
Type T
- Color coded blue and red
- Generates about 40 μV/°C
- −200 to 350 °C