DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

VII Semester

AU3008 Sensors and Actuators

UNIT – 2 - Variable Resistance and Inductance Sensors

2.4 Thermistors

Principle of operation- Construction details- Characteristics and applications of Thermistors

Thermistor - it is derived from the term **THER**Mally sensitive Res**ISTOR**
Thermistors are electrical resistors whose resistance varies significantly with temperature. This property makes them highly sensitive to temperature changes, making them ideal for a wide range of applications.

2.4.1 Principle of operation of thermistor:

The principle of operation of a thermistor is based on **thermoresistivity**. This means that the resistance of the thermistor changes predictably as its temperature varies.

- **Negative Temperature Coefficient (NTC) Thermistors:** The resistance of these thermistors decreases as the temperature increases. This is the most common type of thermistor.
- **Positive Temperature Coefficient (PTC) Thermistors:** The resistance of these thermistors increases as the temperature increases.

This change in resistance can be used to measure temperature or to control temperature-sensitive devices.

2.4.2 Materials of thermistor:

Thermistors are typically made from **semiconducting materials**. These materials have electrical conductivity that falls between that of conductors and insulators.

A. **NTC thermistors** are typically made from **semiconducting materials**, such as **oxides of metals**. Some common materials used for NTC thermistors include:

- **Manganese oxide (MnO2):** This is one of the most commonly used materials for NTC thermistors due to its high sensitivity and stability.
- **Nickel oxide (NiO):** This material is also used for NTC thermistors, especially for applications requiring a wide temperature range.
- **Cobalt oxide (CoO):** This material is used for NTC thermistors in applications where a high temperature coefficient is needed.
- **Iron oxide (Fe2O3):** This material is used for NTC thermistors in applications where a low resistance is required.

B. **PTC thermistors** are typically made from **semiconducting materials**. Some common materials used for PTC thermistors include:

- **Barium titanate (BaTiO3):** This is the most commonly used material for PTC thermistors due to its high Curie temperature and steep resistance change.
- **Strontium titanate (SrTiO3):** This material is also used for PTC thermistors, especially for applications requiring a lower Curie temperature.
- **Lead titanate (PbTiO3):** This material is used for PTC thermistors in applications where a high resistance is required.

The specific material used in a PTC thermistor will depend on the desired temperature range, sensitivity, and other characteristics. For example, PTC thermistors used in high-temperature applications may require materials that can withstand extreme temperatures without degrading.

2.4.3 Temperature Range:

Thermistor type	Standard Temperature Range	Extended Temperature Range
PTC	-40^0 C to 150^0 C	Up to 200^0 C
NTC	-55^0 C to 200^0 C	Up to 300^0 C

The actual operating range may vary depending on the material composition and specific design of the thermistor.

2.4.4 Thermistor Equations:

$$R = R_0 \left[1 + \alpha (T - T_0)\right]$$

represents the resistance-temperature relationship of a thermistor.

R(T): Resistance of the thermistor at temperature T

R_0: Resistance of the thermistor at a reference temperature T_0

α: Temperature coefficient of resistance (TCR)

T: Current temperature

T_0: Reference temperature

This equation essentially states that the resistance of a thermistor changes exponentially with temperature. The temperature coefficient of resistance (α) determines the rate of change.

- **Positive α:** For a PTC (Positive Temperature Coefficient) thermistor, α is positive. This means that as the temperature increases, the resistance also increases exponentially.
- **Negative α:** For an NTC (Negative Temperature Coefficient) thermistor, α is negative. This means that as the temperature increases, the resistance decreases exponentially.

Steinhart-Hart Equation:

- The **Steinhart-Hart equation** is a widely used empirical formula to approximate the resistance of a thermistor as a function of temperature. It provides a more accurate representation than the simpler linear approximation, especially over a wide temperature range.

The **Steinhart-Hart equation of NTC Thermistor**

$$T = \frac{1}{A + B\ln(R) + C[\ln(R)]^3}$$

"T" is in degrees Kelvin and "A", "B", and "C" are Steinhart-Hart **c**oefficients, which are specific constants for each thermistor.

- For **PTC thermistors**, the resistance increases with increasing temperature, and their behavior is typically nonlinear as well.

2.4.5. Constructional Details of Thermistors

- The thermistor consists of a metal tube, leads, and temperature sensing element. The temperature sensing element is the main part of the thermistor, which senses temperature variations enclosed in a metal tube.
- The sensing element is basically a thermal resistor made with sintering (pressing) mixtures of metallic oxides like copper, nickel, cobalt, iron, manganese, and uranium.
- The sensing element is covered with an insulating material before enclosing it with the metal tube.
- Two leads are connected to the temperature sensing element and are brought out of the metal tube.
- The other end of the two leads is connected to one of the arms of the bridge circuit (generally Wheatstone bridge is used) which measures the resistance of the temperature sensing element.

- ❖ The commercial thermistors are made in the form of beads, probes, discs, and rods in a variety of sizes as shown below.
- ❖ Thermistors are highly sensitive to temperature variations, which makes them suitable for precise temperature measurements. They are used for measuring temperatures ranging from -100°C to +300°C.

2.4.6 Types of Thermistor based on Material

The thermistor can be shaped into three different types. Therefore, they are divided into the following types:

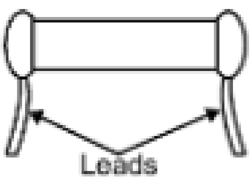
- Bead Thermistor
- Disc and Chip Style thermistor
- Cylindrical Thermistor
- Metalized surface thermistor

Bead Thermistor

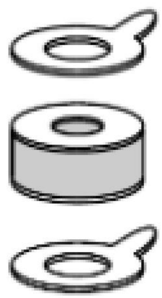
- ❖ *shape of a bead*
- ❖ *better stability with a quick response time.*

Disc & Chip Thermistor

- ❖ *The disc shape is made by pressing material under high pressure with diameter range from 2.5 mm to 25mm.*
- ❖ *It has a larger metal surface. Due to its larger surface, they have a slower response time*



Rod Type



Washer Type

Such thermistor's body is pressed into a cylindrical shape. They have a larger size as compared to other types. They are robust and reliable.

***Washer-type thermistors** are a specialized type of thermistor designed in the shape of a washer or disk. This unique configuration offers several advantages, making them suitable for a wide range of applications.*

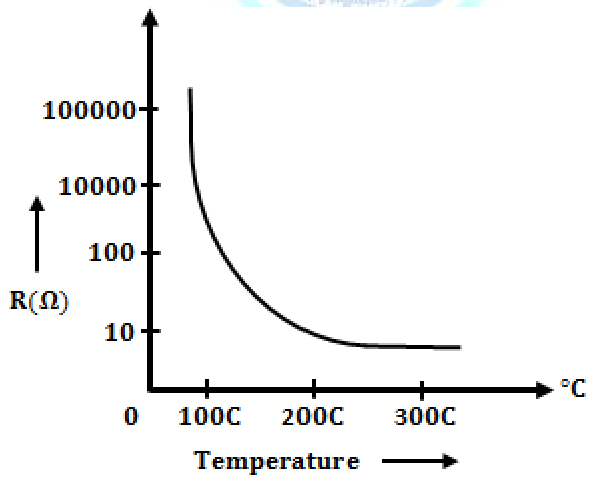
2.4.7 Working and Characteristics of Thermistors

Negative Temperature Coefficient or NTC Thermistor

- NTC thermistors have a negative temperature coefficient there will be an inverse relationship between resistance and temperature i.e. if the temperature of the thermistor increases the resistance decreases.

- This type of thermistors are widely used for measuring temperature. The resistance temperature relation can be expressed by the following relationship,

$$R_t = R_o \, e^{\beta\left(\frac{1}{t} - \frac{1}{t_o}\right)}$$

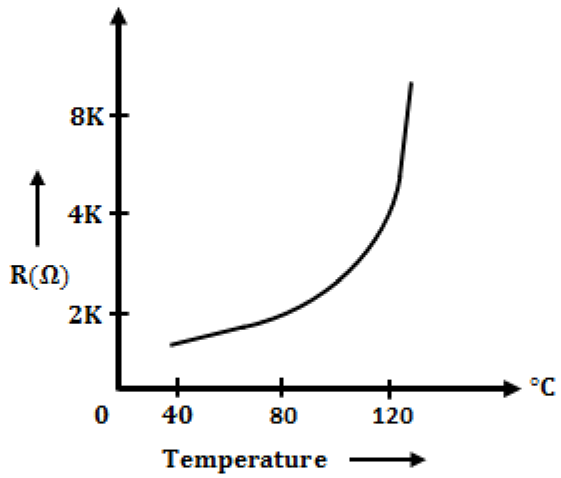


Resistance Temperature Characteristics of NTC Thermistor

- The curve above shows the resistance variation with the temperature of an NTC thermistor. The change is non-linear. They are available in values ranging from few ohms to megaohms.

Positive Temperature Coefficient or PTC Thermistor:

- This type of thermistors has a positive temperature coefficient i.e., their resistance increases with an increase in temperature. It is shown in the below figure.



Resistance Temperature Characteristics of PTC Thermistor

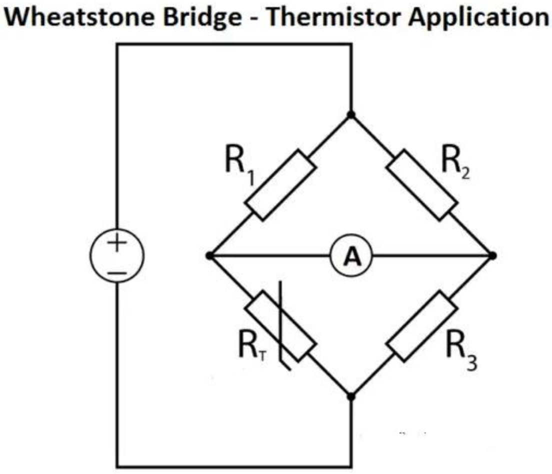
- These are usually made from titanates of barium, lead, and strontium. Positive temperature coefficient thermistors are mainly used as protective elements in electric machinery for the protection of windings in transformers and motors etc.

- They are used as a device to protect all kinds of electrical apparatus against overheating. If the apparatus is overheated PTC thermistor resistance raises sharply. The relay coil would be de-energized and the apparatus is disconnected from the supply.

2.4.8 Working of Thermistor :

- Initially, a known value of current is given to the thermistor sensing element, and resistance of the thermistor sensing element is calculated. Then after the thermistor is placed in media whose temperature is to be measured.

- Now when the thermistor is placed in the media whose temperature is higher than the temperature of the sensing element. It causes heat up the sensing element and the temperature of the sensing element increases.



- A very basic circuit that uses Thermistor for temperature measurement is shown below. It is nothing but a Wheatstone bridge. Initially, all the 4 resistors (one of them being Thermistor) are balanced, that is there won't be any current through the ammeter.
- A change in temperature will obviously change the resistance of the Thermistor and hence a current will flow through the ammeter.

2.4.9 Applications of Thermistors

Thermistors, with their ability to accurately measure temperature, are essential components in modern automobiles, serving a variety of critical functions. Here are some key automotive applications of thermistors:

<u>**Automotive Applications**</u>:

- **Engine temperature monitoring:** Thermistors are used to measure the temperature of the engine coolant, ensuring optimal engine performance and preventing overheating.
- **Airflow sensing:** Thermistors can be used to measure the temperature of incoming air, helping to adjust the air-fuel ratio for efficient combustion.

- **Exhaust gas temperature sensing:** Thermistors can monitor the temperature of exhaust gases to optimize emissions control and catalytic converter performance.

Medical Applications:

- **Diagnostic equipment:** Measuring body temperature, blood temperature, and other physiological parameters.
- **Patient monitoring:** Monitoring temperature to detect infections or other health issues.
- **Laboratory equipment:** Controlling temperature in incubators, water baths, and other laboratory instruments.

Other Applications:

- **Environmental monitoring:** Measuring temperature in weather stations, oceanography, and climate studies.
- **Security systems:** Detecting intrusion by monitoring temperature changes.
- **Energy management:** Optimizing energy consumption by monitoring temperature in buildings and industrial facilities

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