1.4.4: Resistive Temperature Sensors

Overview:

Most people have an intuitive concept of temperature, heat or cold is sensed directly via the sense of touch. Temperature is also an extremely important quantity from the standpoint of engineering and physics, in these disciplines we require a more technical definition of temperature. Temperature, engineering terms, provides a measure of the amount of internal kinetic energy that the molecules in an object have. This property governs a number of important physical phenomena, including:

- *Heat transfer.* Heat tends to flow from regions of high temperature to low temperature. The field of heat transfer, therefore, relies heavily upon determining the temperature distribution in a material.
- *Thermodynamics.* Temperature is a primary parameter which determines the thermodynamic state of liquids and gasses. For example, the amount of propane which can safely be stored in a given tank is a strong function of the temperatures that the gas will be subjected to; if the temperature exceeds specified levels, the tank may rupture – with potentially disastrous consequences.

Due to the extreme importance of temperature in many engineering analysis, temperature is one of the most commonly measured physical parameters. Many approaches have been developed to measure temperature. In this module, we will discuss temperature measurement processes which rely upon temperature-induced changes in electrical resistance. Measuring electrical resistance under these circumstances, allows us to infer temperature. Electrical resistance approaches to temperature measurement are extremely popular, since the signals resulting from these types of measurements are readily recorded, transmitted and analyzed.

Two relatively common approaches toward electrical resistance-based temperature measurements are resistive temperature detectors (RTDs) and thermistors. Thermistors are somewhat more widely used than RTDs, primarily because thermistors are considerably less expensive than RTDs. This module is by no means intended to be a comprehensive discussion of how to use either RTDs or therrmocouples. We restrict ourselves to a presentation of the principle concepts relative to the operation of these types of temperature measurement device, along with some general information about how these instruments are used in practice.

Before beginning this module, you should be able to:

- Perform basic algebra
- Analyze resistive electrical circuits

After completing this module, you should be able to:

- Write an approximate linear relationship governing the temperature-resistance characteristic of RTDs
- Sketch an electrical circuit to convert resistance change to voltage change
- Write a nonlinear temperature-resistance relationship for thermistors
- List two sources of error commonly arising in resistive temperature measurements

References:

1. Holman, J.P., Experimental Methods for Engineers, 3rd edition, McGraw-Hill Book Company, 1978.

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Resistive Temperature Detectors:

Many materials, especially metals, have resistivities which increase as temperature increases. Resistive Temperature Detectors (RTDs) utilize this property to provide a temperature measurement. RTDs can be made by winding a thin wire into a coil or depositing a thin film of metal on a plastic or ceramic substrate. This wire or film is then exposed to the temperature being measured; as the temperature increases, the resistivity of the wire or film increases, and the overall electrical resistance of the device increases. Platinum is commonly used in RTDs, since its resistivity varies linearly with temperature over a wide temperature range. RTDs have a number of advantages over other types of temperature measurements: their response is extremely linear over a wide temperature range and their readings are extremely stable. Among their disadvantages is their high cost: the high cost of platinum makes RTDs relatively expensive compared to other temperature measurement devices.

As noted above, the resistance vs. temperature relation is approximately linear. This relationship is commonly defined in terms of a linear temperature coefficient of resistance, α, as follows:

$$R = R_{nom} + \alpha R_{nom}(T - T_{nom}) \tag{1}$$

where R is the resistance at the temperature T and R_{nom} is the resistance at some nominal (reference) temperature T_{nom} (often taken to be some convenient temperature such as 0°C or 0°F). This can be rearranged to determine the temperature from the measured resistance:

$$T = T_{nom} + \left(\frac{R - R_{nom}}{\alpha \cdot R_{nom}} \right) \tag{2}$$

The temperature coefficient of resistance for platinum is approximately 0.00392 (reference [1]), though this value depends upon the grade of platinum used. It is always important to determine α accurately for the particular RTD being used, especially if large ranges in temperature are to be measured.

Over very large temperature ranges, the linear relationship of equation (1) between resistance and temperature may not be appropriate. In these cases, a quadratic relationship is generally employed:

$$R = R_{nom}[1 + a(T - T_{nom}) + b(T - T_{nom})^2] \tag{3}$$

where R, R_{nom}, T, and T_{nom} are as defined above. a and b are experimentally determined constants.

RTD Signal Conditioning:

The resistance changes of RTDs are usually converted to a voltage change by electrical circuitry. Voltage levels have the advantage over resistances in that voltages can be readily transmitted, recorded, and used for control purposes. The resistance-to-voltage conversion is normally performed by a Wheatstone bridge circuit; a very simple Wheatstone bridge circuit is shown in Figure 1. In the bridge circuit of Figure 1, the RTD resistance is represented by a resistor with resistance $R+\Delta R$. The resistance R is the nominal resistance of the RTD, the resistance ΔR represents the change in resistance of the strain gage due to some temperature change. There are three fixed resistors in the bridge circuit of Figure 1; these resistors all have the same resistance as the nominal resistance of the RTD. A fixed voltage, Vs, is applied to the circuit as shown. The output voltage, v_{ab}, is the

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voltage which is used to represent the change in resistance of the RTD. Without proof, we claim that the output voltage is:

$$v_{ab} = \frac{\Delta R}{2(2R + \Delta R)} \cdot V_S \tag{4}$$

if $\Delta R << R$, which is the usual case for RTDs, this simplifies to:

$$v_{ab} \approx \frac{V_s}{4R} \Delta R \tag{5}$$

and the output voltage is linearly related to the change in resistance of the RTD. Since the RTD resistance is linearly related to the temperature, the output voltage is thus a linear function of temperature.

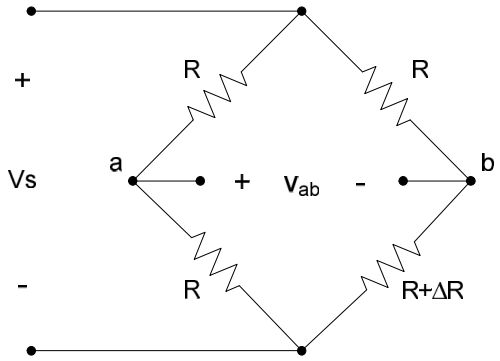


Figure 1. Wheatstone bridge circuit.

Thermistors:

Thermistors are semiconductor devices whose resistance, like RTDs, varies with temperature. In fact, thermistors can be considered to be a special case of an RTD. Thermistors, however, have a number of properties which distinguish them from RTDs as presented in the previous section. These differences are outlined below:

- The resistance of thermistors commonly decreases as temperature increases. Thermistors with this type of resistance-temperature characteristic are called Negative Temperature Coefficient (NTC) thermistors. Thermistors whose resistance increases with temperature are available; these are called Positive Temperature Coefficient (PTC) thermistors.
- Thermistors generally do not exhibit a linear relationship between temperature and resistance. The relationship between temperature and resistance for a thermistor is commonly modeled by an exponential relation. Reference [1], for example, provides the following resistance-temperature relationship:

$$R = R_{nom} e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_{nom}}\right)\right]} \tag{6}$$

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where R is the resistance at the temperature T and R_{nom} is the resistance at some reference temperature, T_{nom}. This nonlinear resistance-termperature relation is a significant drawback to the use of thermistors; however, the thermistors' advantages often outweigh this disadvantage, making thermistors one of the most common choices for temperature measurement devices.

- Because of the thermistors' nonlinear resistance-temperature relation, thermistors are useful over smaller temperature ranges than RTDs.
- Thermistors generally have a much higher sensitivity than RTDs – the resistance change resulting from a given temperature variation is considerably larger for a thermistor than for an RTD.
- Thermistors generally have a faster temperature response than RTDs. This makes them a better choice for time-varying (transient) temperature changes than RTDs.
- Thermistors are less expensive than RTDs.

Thermistor Signal Conditioning:

A bridge circuit like that of Figure 1, with the thermistor used for the $R+\Delta R$ resistance, is often used to convert the thermistor's change in resistance to a voltage change. Unlike the RTD, however, the output voltage vs. temperature relation is generally nonlinear. Also, if an NTC thermistor is used, the output voltage of the circuit of Figure 1 will decrease as temperature increases. Modifications to the bridge circuit of Figure 1 can alleviate both of these drawbacks – bridge circuits using a second thermistor can help provide a more linear response, while switching the polarity of the output voltage will result in an output voltage which increases with increasing temperature.

Issues associated with resistive temperature measurement:

Several issues must be considered when using resistive temperature measurement devices. When using a bridge circuit like that shown in Figure 1, the externally supplied voltage Vs will result in some current flowing through the resistive temperature measurement device. This current will induce heating of the resistive temperature measurement device, due to the resistive power dissipation in the device. Care must be taken that this so-called *self heating* of the device does not introduce excessive heating in the device itself, which can invalidate the temperature measurement.

Another common source of error in electrical resistance temperature measurements is the resistance of the leads connecting the device to the bridge circuit used to convert the resistance change to a voltage change. Alternate bridge circuits can compensate for this effect.

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