

Tutorial 3

Chapter 6 Temperature Measurement

6.1 A type-K thermocouple is exposed to a temperature of 1200°C . If the indicator is used as the cold junction and its temperature is 50°C use the following figure to calculate the emf indicated. Using the Thermocouple Temperature vs. EMF Tables provided confirm your answer. [47 mV]

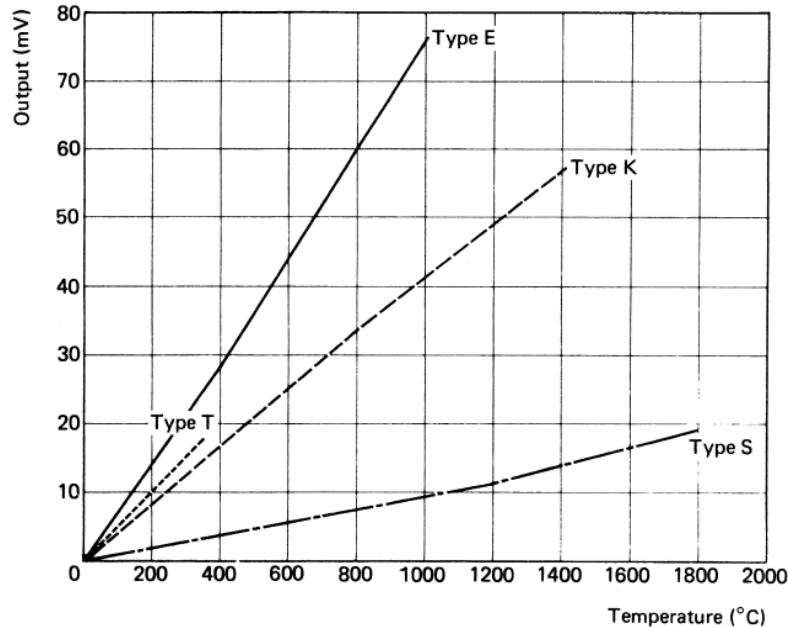


Figure 6.1 Thermocouple characteristics (reference $^{\circ}\text{C}$)

6.2 Using the above figure, determine (a) the sensitivity of the type-T thermocouple in the range of 0°C to 300°C , (b) the sensitivities of the type-E and type-S thermocouples in the range of 400°C to 1000°C . Using the Thermocouple Temperature vs. EMF Tables provided confirm your answers. [0.5 mV/ $^{\circ}\text{C}$] [0.08 mV/ $^{\circ}\text{C}$] [0.01 mV/ $^{\circ}\text{C}$]

6.3 Use the above figure. A type-E thermocouple is connected to a voltmeter whose terminals are at 50°C . If the potentiometer reading is 60 mV, what is the temperature at the thermocouple hot junction? Using the Thermocouple Temperature vs. EMF Tables provided confirm your answers. [64 mV and 850°C]

6.4 (RTD) A platinum resistance thermometer has a resistance of $138.5\ \Omega$ at 100°C . If its resistance increases to $281\ \Omega$ when it is in contact with a hot gas, determine the temperature of the gas. The resistance can be taken as $100\ \Omega$ at 0°C [465.4°C].

6.5 Explain the principle of operation of the platinum resistance thermometer (RTD-100). What are its advantages and disadvantages over the liquid-in-glass thermometer?

6.6 An RTD has α (at 20°C) = $0.004\ /^{\circ}\text{C}$. If $R = 106\ \Omega$ at 20°C , find the resistance at 25°C . α is assumed to be constant over the range.

6.7 The RTD of **Exercise 6** is used in the Wheatstone bridge circuit as shown in the following figure. If $R_1 = R_2 = R_3 = 100 \Omega$ and the supply voltage is 10.0 V, calculate the voltage the detector must be able to resolve in order to resolve a 1.0°C change in temperature.

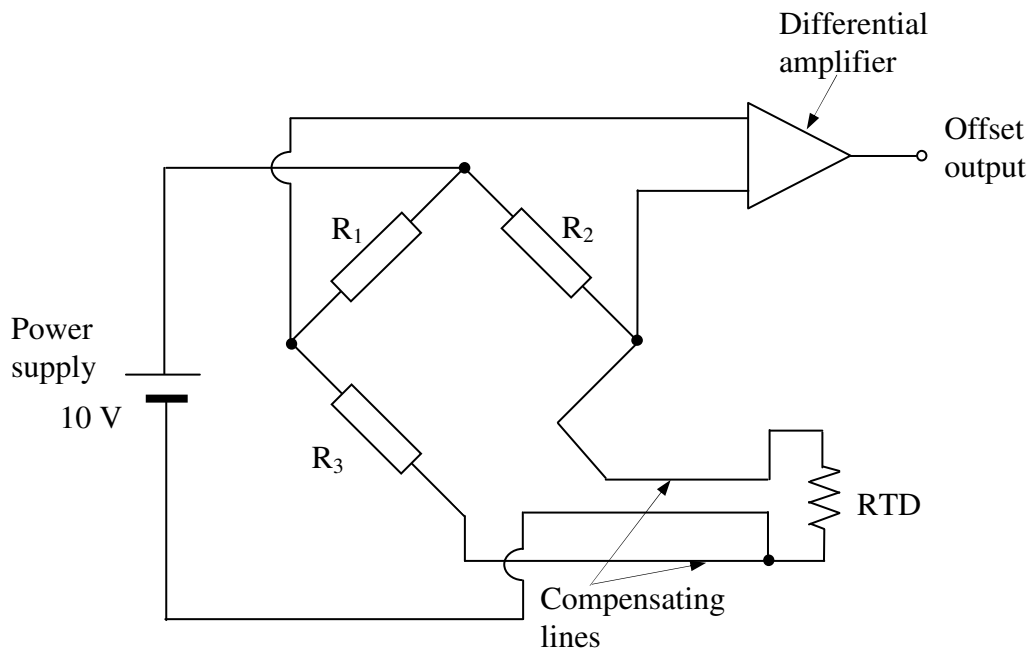


Figure 1.2 for Exercise 6.7

6.8 An RTD has $\alpha_0 = 0.005 / ^\circ\text{C}$, $R = 500 \Omega$ and a dissipation constant of $P_D = 30 \text{ mW}/^\circ\text{C}$ at 20°C . The RTD is used in a bridge circuit as shown in the following figure, with $R_1 = R_2 = 500 \Omega$, and R_3 is a variable resistor used to null the bridge. If the supply is 10 V and the RTD is placed in an ice bath at 0°C :

a) Find the value of R_3 to null the bridge [$R_3 = 454.5 \Omega$].

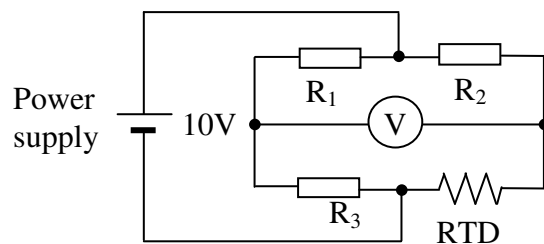


Figure 1.3 RTD with a bridge circuit for Exercise 1.8

b) Find the output voltage measured by a voltmeter ($R_v = \infty$) with the above value of R_3 if the temperature is 100°C . Consider the effect of the self-heating and calculate the error of the RTD at 100°C .

6.9 At any particular instant, a resistance thermometer indicates a temperature T_2 of 50°C while the actual temperature T_1 is 100°C . If the dynamic relationship for the resistance thermometer is given by

$$\frac{dT_2}{dt} = k(T_1 - T_2) \text{ where } k = 0.2 \text{ s}^{-1}$$

Determine the time constant for the thermometer.

6.10 (Thermocouples) Find the emf for a material with $\alpha = 50 \mu\text{V}/^\circ\text{C}$ if the junction temperatures are 20°C and 100°C .

Hints: The thermoelectric effect is expressed by the following equation:

$$\varepsilon = \int_{T_1}^{T_2} (Q_A - Q_B) dT$$

where

ε = emf (also called *Seebeck emf*) produced in volts

T_1, T_2 = junction temperatures in K

Q_A, Q_B = thermal transport constants of the two metals

This equation, which described the Seebeck effect, shows that the emf produced is proportional to the difference in temperature and, further, to the difference in the metallic thermal transport constants. Thus, if the metals are the same, the emf is zero, and if the temperature are the same, the emf is zero.

In practice, it is found that the two constants, Q_A and Q_B , are nearly independent of temperature and that an approximate linear relationship exists as

$$\varepsilon = \alpha(T_2 - T_1)$$

where α = constant in V/K

T_1, T_2 = junction temperatures in K

6.11. A voltage of 23.72 mV is measured with a type K thermocouple at a 0°C reference. Find the temperature of the measurement junction. [572.1 $^\circ\text{C}$]

Hints: use the attached sheet with the following interpolation equations:

Temperature:

$$T_M = T_L + \left[\frac{T_H - T_L}{V_H - V_L} \right] (V_M - V_L)$$

where V_M = measured voltage that lies between a higher voltage, V_H , and a lower voltage, V_L , which are in the tables. The temperatures corresponding to these voltages are T_H and T_L , respectively.

Voltage:

$$V_M = V_L + \left[\frac{V_H - V_L}{T_H - T_L} \right] (T_M - T_L)$$

6.12 Find the voltage of a type J thermocouple with a 0°C reference if the hot junction temperature is -172°C. [-7.18°C]

Appendix

RTD Signal Conditioning: In view of the very small fractional changes of resistance with temperature (0.4%), the RTD is generally used in a bridge circuit. The following figure illustrates the essential features of such a system. The compensation line in R₃ leg of the bridge is required when the lead lengths are so long that thermal gradients along the RTD leg may cause changes in line resistance. By using the compensation line, the same resistance changes also appear on the R₃ side of the bridge and cause no net shift in the bridge null.

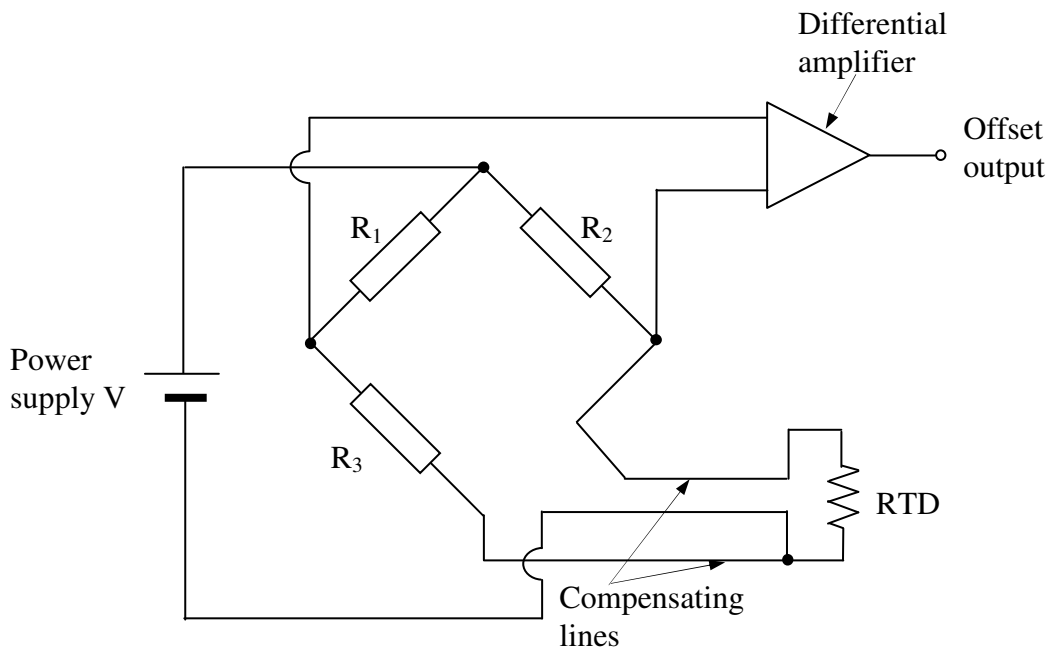


Figure 6.4 The compensating lines in a typical RTD signal-conditioning circuit

Dissipation Constant: Because an RTD is a resistance, there is an I^2R power dissipated by the device itself that causes a light heating effect, a self-heating. This may also cause an erroneous reading or even upset the environment in delicate measurement condition. Thus, the current through the RTD must be kept sufficiently low and constant to avoid self-heating. Typically, a dissipation constant is provided in RTD specifications. This number relates the power required to raise the RTD temperature by one degree of temperature. Thus, a 25-mW/°C dissipation constant shows that if I^2R power losses in the RTD equal 25 mW, the RTD will be heated by 1.0°C.

The dissipation constant is usually specified under two conditions: free air and a well-stirred oil bath. This is because of the difference in capacity of the medium to carry heat away from the device. The self-heating temperature rise can be found from the power dissipated by the RTD, and the dissipation constant from:

$$\Delta T = \frac{P}{P_D}$$

where ΔT = temperature rise because of self-heating in $^{\circ}\text{C}$
 P = power dissipated in the RTD from the circuit in W
 P_D = dissipation constant of the RTD in $\text{W}/^{\circ}\text{C}$

Example

An RTD has $\alpha_0 = 0.005/^{\circ}\text{C}$, $R = 500 \Omega$ and a dissipation constant of $P_D = 30 \text{ mW}/^{\circ}\text{C}$ at 20°C . The RTD is used in a bridge circuit as in **Fig. 6.4**, with $R_1 = R_2 = 500 \Omega$ and R_3 is a variable resistor used to null the bridge. If the supply is 10 V and the RTD is placed in a bath at 0°C , find the value of R_3 to null the bridge.

Solution

First we find the value of the RTD resistance at 0°C without including the effects of dissipation. From Equation (5) (Chapter 6) we get

$$R = 500[1 + 0.005(0 - 20)] \Omega$$

$$R = 450 \Omega$$

Except for the effects of self-heating, we would expect the bridge to null with R_3 equal to 450Ω also. Let's see that self-heating does to this problem. First, we find the power dissipated in the RTD from the circuit, assuming the resistance is still 450Ω . The power is

$$P = I^2 R$$

and the current I to three significant figures is found from:

$$I = \frac{10}{500 + 450} = 0.011 \text{ A}$$

so that the power is

$$P = (0.011)^2(450) = 0.054 \text{ W}$$

We get the temperature rise from

$$\Delta T = \frac{P}{P_D} = \frac{0.054}{0.030} = 1.8^{\circ}\text{C}$$

Thus the RTD is not actually at the bath temperature of 0°C , but at a temperature of 1.8°C . We must find the RTD equation resistance from (5) as

$$R = 500[1 + 0.005(1.8 - 20)] \Omega$$

$$R = 454.5 \Omega$$

Thus, the bridge will null with $R_3 = 454.5 \Omega$.