Temperature Sensors

Temperature is one of the most commonly measured variables and it is therefore not surprising that there are many ways of sensing it. Heat is transferred by three methods: convection, conduction, and radiation. Temperature sensing can be done either through direct contact with the heating source, or remotely, without direct contact with the source using radiated energy instead. Radiated heat energy is an electromagnetic wave and (mostly infrared) and much of the discussion of light sensing will apply. Contact sensors use conduction or convection, while remote sensing uses radiation as the primary method of heat transfer.

The traditional method for measuring temperature is the thermometer, which relies on the expansion of material with heat. This is unfortunately not easy to convert to a sensor for remote monitoring.

Another type of heat sensitive sensor bases its measurement on the ability of a material to respond to radiant heat energy. When the material is heated, the surface of the material gives off light in the infrared range. This light is a direct indication of the energy absorbed. And since temperature and energy are related, we can reliably determine the temperature of the object.

Another type of heat sensor bases its measurement on the principle that different metals expand and contract at different rates. A ***bimetal strip*** is composed of a strip of metal bonded on top of another strip of metal. As the material heats or cools the metals expand or contract at different rates causing the material to bend one direction or another. This movement can then be translated into voltage through the use of any position measuring transducer. This technique is also often used to make a simple detector and used in a motor overload circuit, toaster, furnace etc.

Accurate temperature measurements are required in many other measurement systems such as process control and instrumentation applications. In most cases, because of low level non-linear outputs, the sensor output must be properly conditioned and amplified before further processing can occur.

Except for IC sensors, all temperature sensors have nonlinear transfer functions. In the past, complex analog conditioning circuits were designed to correct for the sensor nonlinearity. These circuits often required manual calibration and precision resistors to achieve the desired accuracy. Today these sensor outputs may be digitized directly by high resolution ADCs. Linearization and calibration is then performed digitally, thereby reducing cost and complexity.

Heat transfer is the movement of energy from one object to another. The energy transferred is dependent upon the area of the object and the absolute temperature of the object.

In this class we are mainly going to concentrate on the sensing of temperature through thermoresistivity or thermoelectricity.

Physics and units

Temperature is a measure of the kinetic energy of the molecules of a substance. If there is no kinetic energy then we say that the temperature is at *absolute zero* which is defined as 0 degrees Kelvin or 0 degrees Rankine. Other than absolute zero the temperature scales are defined as an arbitrary division of units between fixed points. The Celsius (Kelvin) scale divides the range between freezing and boiling water into 100 units. The Fahrenheit (Rankine) scale was originally based on the temperature of a particular cave in midwinter (0° F) and the body temperature of a cow (100° F) Absolute zero is a fixed distance from these calibration points. 0K = -273.15° C and 0 Rankine = -459.67° F. The conversion between Fahrenheit and Celsius is well known. Fahrenheit degrees are *defined as* 5/9 of a Celsius degree and then one merely adjusts for the 32° offset.

Thermoresistivity

Thermoresistivity is based on the change of resistance of a material through the application of heat. Common sensors based on this principle are the resistance temperature detector (RTD), the thermistor, semiconductor bandgap sensors and the diode junction sensor.

Resistance Temperature Detector

The resistance temperature detector is a sensor made from a pure wire-wound metal having a positive temperature coefficient. A metal that has a positive temperature coefficient is one that increases its resistance with temperature. This is the case with most metals. The metals used are most commonly nickel, platinum, and certain alloyed forms of copper. Of these three, platinum is probably used most frequently because it has a linear output. It is unfortunately very expensive as well. Platinum is a very stable metal, which makes it very reliable and predictable to work with. A very common probe is the Pt100. It is a platinum probe designed to have 100Ω of resistance at 0 ℃. Nickel is more sensitive than platinum however it is less linear.

RTD's can be used over a wide temperature range from 4K (-268 ℃) to about 1000 ℃. Practical: Pt –200 ℃ to +850 ℃, Copper –200 ℃ to +260 ℃, Nickel –80 ℃ to +320 ℃. The relationship between temp and resistance is not linear and can be modeled with a standard polynomial equation

$$\Delta R/R_{REF} = \gamma(T-T_{REF}) + \gamma_2(T-T_{REF})^2 + \gamma_3(T-T_{REF})^3 + \ldots + \gamma_N(T-T_{REF})^N.$$

Where:

R_{REF} and T_{REF} are the reference resistance and temp

γ_i are temperature coefficients for the material

This equation is an arbitrary mathematical model to predict (not explain) the observed behavior of the sensor. We simply fit an nth order polynomial to resistance and temperature data. Most statistical software packages have standard functions for doing this. If we ignore higher terms we have a linear model using just the γ term. IE

$$\Delta R/R_{REF} = \gamma(T-T_{REF})$$

This is often an acceptable approximation over limited ranges especially for very stable metals such as Platinum. Slope over 0 ℃ to 100 ℃ = 0.385 Ω / ℃ (European standard) or 0.3925 Ω / ℃ (US standard). This low temperature coefficient requires high performance signal conditioning circuitry to convert into a signal suitable for a computer or a display. Accuracy of commercial probes is about 0.1% to 1.0%.

RTDs are passive sensors, requiring a power supply to convert the resistance change into a voltage or current. The simple circuit shown in figure 1 can do this

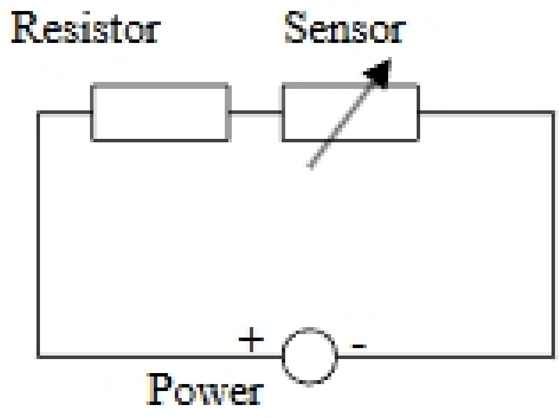

Figure 1 A simple RTD transducer.

RTDs are subject to "self heating" especially in still air. The current heats the probe and the probe senses this rise in temperature as well as the measured temperature. Decreasing the current through the RTD helps to minimize self-heating but also decreases sensitivity. Manufacturers usually provide information on the self-heating to be expected in a particular sensor.

The simple circuit in figure 1 will be subject to self-heating problems as well as having poor sensitivity. The circuit can be improved as shown in figure 2. For greater accuracy and sensitivity RTD's are commonly used with Wheatstone bridges.

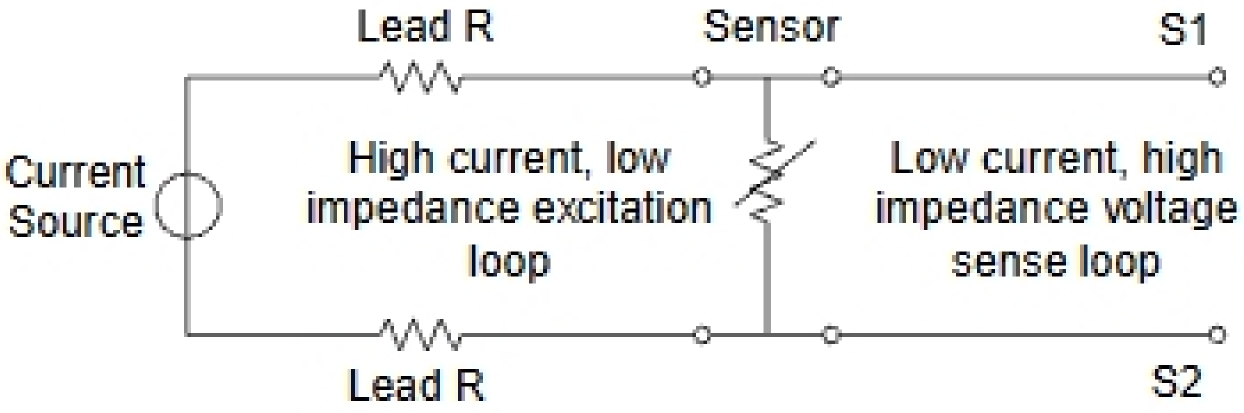

Figure 2 Four wire connections for RTD sensor

RTDs are more sensitive than thermocouples but less sensitive than thermistors. The wire-wound RTD has increased sensitivity and a response time of 0.1 to 10 seconds. Response time is a function of thermal mass. The curve of resistance vs. temperature is available in the OMEGA temperature catalog (~$100 for basic probe). If a fast response time is needed, RTDs can be constructed from a thin film of Pt on a substrate. This device lets you measure the temperature changes hundreds of times per second in processes such as injection molding or machining. (~$20 for probe). One disadvantage of the thin film Pt probe is that it is fragile.

The following table is from Pallas-Areny and Webster, table 2.3. The table lists the characteristics of certain metals. This data clearly shows the wide operating range of platinum and the sensitivity of Nickel.. Platinum has the best overall performance and,