Chapter 15

An introduction to resistance temperature detectors

TEC/NOT/023

This paper introduces temperature measurement using Resistance Temperature Detectors (RTD). The following topics are discussed:

15.1 Introduction

In 1871, Sir William Siemens proposed a thermometer comprising a metallic conductor as the thermometric medium, whose resistance changes with temperature. He chose platinum as the element for the resistance thermometer. Platinum does not oxidize at high temperatures and has a relatively uniform change in resistance with temperature over a large range. The Platinum Resistance Temperature Detector is still used today as an interpolation standard from the oxygen point.

15.2 Overview

An RTD is a general term for any device that senses temperature by measuring the change in resistance of a material. The resistivity (ρ) of a material is directly proportional to its resistance (R),

$$R = \rho(l/A)$$

where l is the length of the wire and A is the cross sectional area. The resistivity of a material is also dependant on temperature. The resistance of a metal increases with temperature and at higher temperatures, atoms move more rapidly and are arranged in a less orderly fashion, as shown in the following figure, creating a larger interference to the flow of electrons. If the temperature change is gradual, the resistivity of a metal increases almost linearly with temperature. That is,

$$\rho_T = \rho_0(1 + \alpha\Delta T)$$

where ρ_0 is the resistivity at some reference temperature (such as 0°C or 20°C), ρ_T is the resistivity at a temperature ΔT above the reference temperature, and α is the temperature coefficient of resistivity

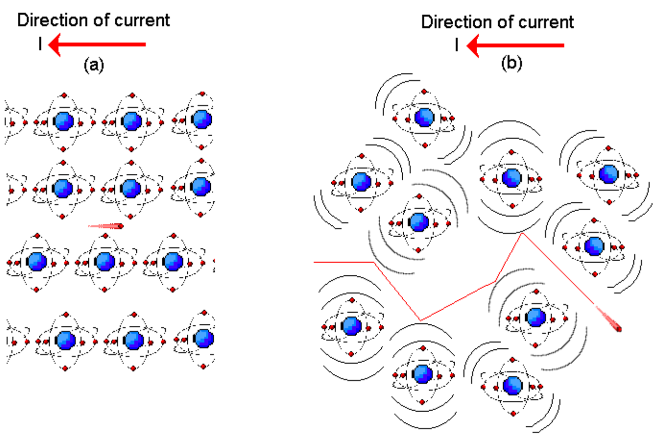
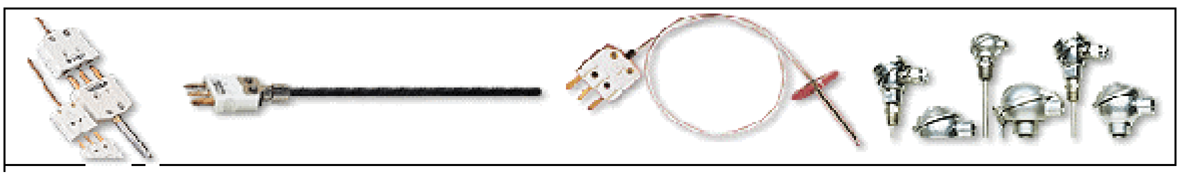


Figure 15-1: (a) Atoms in a metal; (b) Atoms in a metal at higher temperature

All metals produce a positive change in resistance for a positive change in temperature, which is, of course, the main function of an RTD. System error is minimized when the nominal value of the RTD resistance being used is large, that is, a metal wire with a high resistivity. The lower the resistivity of a metal, the more material is required. The following table lists the resistivities of common RTD materials.

Table 15-1: Metal Resistivities

Metal		Resistivity Ω m
Gold	**Au**	2.349×10^{-8}
Silver	**Ag**	1.591×10^{-8}
Copper	**Cu**	1.664×10^{-8}
Platinum	**Pt**	1.059×10^{-7}
Tungsten	**W**	5.491×10^{-8}
Nickel	**Ni**	6.842×10^{-8}



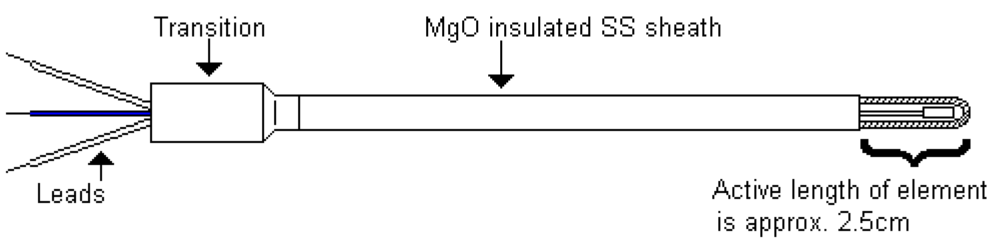


Figure 15-2: Resistance temperature detectors

An RTD probe is an assembly composed of a resistance element, a sheath, lead wire and a termination or connection. There are several very important details that must be specified in order to properly identify the characteristics of an RTD:

- Material of resistance element (platinum, nickel, and so on)
- Temperature coefficient
- Nominal resistance
- Temperature range of application
- Physical dimensions or size restrictions
- Accuracy

Resistance thermometers can be used for a wide variety of industrial applications. A high electrical output can be obtained by using the RTD with many types of simple resistance bridges. This high output can then be fed directly into recorders, temperature controllers, transmitters, or digital readouts, which can be calibrated to read very precise increments of temperature over wide dynamic ranges.

15.3 RTD specifications

The Resistance-Temperature (R-T) curves of pure metals, namely platinum and nickel, over definite spans, are relatively linear making them ideal materials for the elements in resistance thermometers. RTDs can also be constructed from copper or nickel/iron. Each metal has a different a-coefficient and operating range. An RTD's a-coefficient must be matched to its instrumentation or an error of several degrees may occur.

Platinum is by far the most popular metal used due to its linearity with temperature. The R-T relationship of some common RTD materials are illustrated in the following figure, where the y-axis is the normalized resistance with respect to resistance at 0°C (32°F), x-axis is the temperature.

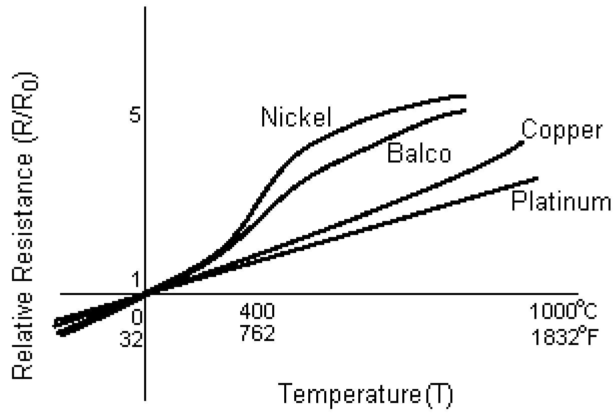


Figure 15-3: Resistance-Temperature relationship for some RTD materials

The temperature coefficient of an element is a physical and electrical property of the material. This is a term that describes the average resistance change per unit of temperature from ice point to the boiling point of water. Different organizations have adopted different temperature coefficients as their standard. Laboratory resistance temperature detectors of pure platinum, fully annealed and strain free have been chosen as the International Standard of Temperature Measurement from liquid oxygen [(LO2)-182.97°C] to the melting point of antimony [(Sb) + 630.5°C]. Platinum resistance wire has been generally acknowledged as the standard for accuracy and repeatability in a temperature sensor; it is the standard interpolation device between critical temperatures from -259°C to 631°C. Temperature coefficient: 0.003915 W°C-1 and 0.00385 W°C-1. (0.00385 or DIN standard has been adopted as the World and USA standard.) The following table compares several RTD materials.

Table 15-2: RTD material specifications

Material	Temp Range (°C)	~T.C.%/°C at 25°C
Platinum	-200 to +850	0.39
Nickel	-80 to +320	0.67
Copper	-200 to +260	0.38
Nickel-Iron	-200 to +260	0.46

Specifications for temperature range are different for thin film, wire wound and glass encapsulated types. The usual nominal resistance of platinum RTDs is 100W at 0°C. Unfortunately, standards are not identical worldwide, which presents a problem when an RTD, built to one standard, is used with an instrument designed to a different standard. In addition, manufactured tolerances must be considered. Not only do they vary with the manufacturer and the standard, but the tolerances are also affected by the manufacturing process itself.

The DIN and American standards are the most commonly available. The following table describes the most common standards for platinum RTDs.

Table 15-3: Standards for RTDs

Organization	Standard	Alpha Average Temp. Coefficient of Resistance	Nominal Resistance (W) at 0°C
British Standards Association	B.S. 1904: 1984	0.003850	100
Fachnormenausschuss Elektrotechnik in Duetschen	DIN43760-1980	0.003850	100
U.S. Department of Defense	MIL-T-24388	0.00392	100
International Electronical Commission	IEC 751: 1983	0.003850	100

Table 15-3: Standards for RTDs (continued)

Organization	Standard	Alpha Average Temp. Coefficient of Resistance	Nominal Resistance (W) at 0°C
Japanese Standard (Joint Industrial Standards)	JIS C1604-1981	0.003916	100

RTDs come in 2-, 3- and 4-wire probes. The most commonly used RTD is the 3-wire probe, which allows for the compensation of loop resistance by introducing a third wire, known as a reference wire, that is equal in length and size to the two wires connecting the RTD to the readout device. This third wire bypasses the RTD at its junction to one of the other two wires, and allows the readout device to automatically subtract the lead resistance from the overall resistance of the circuit.

Offering even greater potential for accuracy is the 4-wire RTD, which uses two reference wires. The system, however, must be designed to accommodate this design.

In 1826, forty-five years before RTDs, T.J. Seebeck discovered that when wires of different metals are fused at one end and heated, a current flows from one to the other. The electromotive force generated can be quantitatively related to the temperature and hence, the system can be used as a thermometer - known as a thermocouple.

When choosing whether to use a thermocouple or an RTD in a design, the conditions to which the temperature component will be exposed must be considered. RTDs are extremely precise for temperatures below 524°C, and can be more accurate than a thermocouple; however, the reliability of RTDs in service above 524°C is poor. In addition, an RTD's R-T relationship is more linear than the thermocouple's EMF-to-temperature ratio.

For almost all other requirements, however, thermocouples are preferable to RTDs. First, due to its ability to withstand extreme bending and vibration, the thermocouple is more durable than the RTD. Thermocouples also have a wider temperature range (that is, -162°C to 2300°C), as opposed to the RTD's range of -210°C to 524°C. While in theory RTD elements are good for temperatures well in excess of 524°C, in practice, contamination of the element (and thus, loss of accuracy) is common. The following table illustrates the advantages and disadvantages of using RTDs as opposed to thermocouples.

Table 15-4: Comparison of thermocouples and platinum RTDs

	Thermocouple	Platinum RTD
Economics	Probe is cheaper.	Probe is more expensive.
	2-wire transistor can be used in the field if *home run* cables are lengthy, thereby keeping system cost down.	System cost can be lower because RTDs use ordinary copper leads for extension wire.
Operations	Non-linear output signal.	Linear output signal.
	Small size-fast response.	Limited size.
	Higher temperature range.	Lower-use temperature range.
	Point sensing.	No point sensing.
Reliability	More reliable with vibrations and at high pressures (in excess of 10,000 PSIG) and high temps (in excess of 4000°F).	Not as reliable to shocks and vibrations, and poor stability in high temperatures.
Maintenance	More rugged.	Less rugged.
	Not as vulnerable to contamination.	More vulnerable to contamination.
Sensor accuracy	=±2°F or 3/8 of 1% of reading.	More accurate, ±0.1% with compensating loop.
General overall system accuracy	Approx. ±0.75% of reading measured temperature.	Approx. ±0.5% of the measured temperature.
Installation methods	Equal.	Equal with one additional wire.

Table 15-4: Comparison of thermocouples and platinum RTDs (continued)

	Thermocouple	Platinum RTD
Wiring methods	Two-wire, thermocouple material.	Three-wire minimum, copper wire.
Terminations	Same.	Same.
Monitoring equipment	Readily available.	Readily available.
	Monitors sensor output only and compensates for cold junction temperature.	Sends power to field sensor before sensor can be monitored.
	Reads sensor output only (for temperature).	Interprets lead wire resistance change as temperature change if 3- or 4-wire systems are not used.

RTDs offer stable output within broad temperature ranges, can be recalibrated for verifiable accuracy, are stable over the long term, follow a more linear curve than thermocouples, have high sensitivity, and provide accurate reading over narrow temperature spans. The KAD/ADC/019/100 and KAD/ADC/013/B modules have been designed to take temperature samples from RTDs. This was a specification set out by the customer, which was duly incorporated into the above-mentioned modules.

15.4 References

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