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Experiment 7

Resistance Temperature Detector (RTD)

RTD (Resistance Temperature Detector)

Objectives

Upon completion of the study and laboratory experimental measurements, the student will be able to:
1. Describe the materials and their temperature coefficients used in RTD devices.
2. Describe how RTD elements are used for the measurement of temperature.
3. Describe the overall characteristics and construction of RTD devices.
4. Describe the use of the RTD sensor in a bridge circuit.

Theory

Resistance temperature detector (RTD) is another temperature sensing transducer which can be used to measure high temperatures' basic physical property of a metal is that its electrical resistivity changes with temperature. All RTD's are based on this principle. The heart of the RTD is the resistance element. RTD has a positive coefficient, i.e, when the temperature of the RTD increases, its resistance also increases. Several varieties of semi-supported wire-wound fully supported bifilar wound glass, and thin film type elements. the picture below shows several types of RTD`s.

Through years of experience, the characteristics of various metals and their alloys have been learned, and their temperature vs. resistance relationships are available in look-up tables. Some metals have a very predictable change of resistance for a given change of temperature; these are the metals that are most commonly chosen for fabricating an RTD. See figure (1). A precision resistor is made from one of these metals to a nominal ohmic value at a specified temperature. By measuring its resistance at some unknown temperature and comparing this value to the resistor's nominal value, the change in resistance is determined. Because the temperature vs. resistance characteristics are also known, the change in temperature from the point initially specified can be calculated. We now have a practical temperature sensor, which in its bare form (the resistor) is commonly referred to as a resistance element.

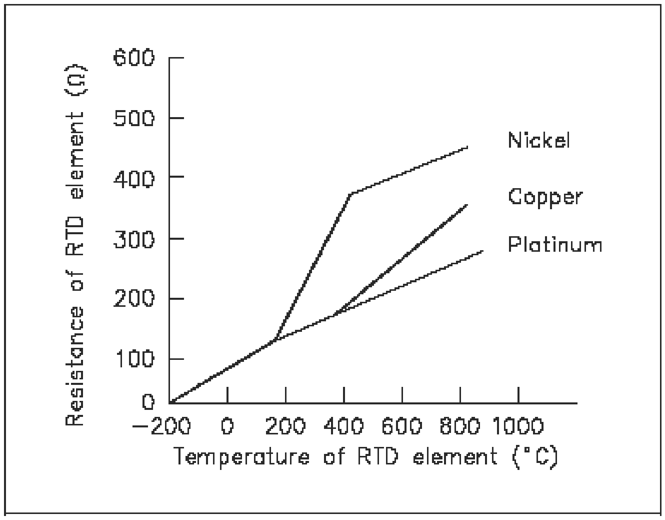


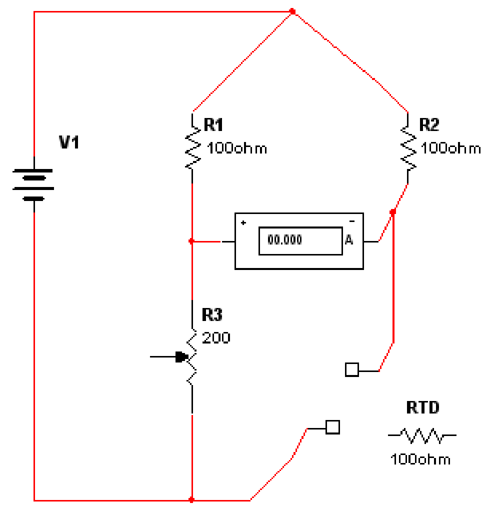
Figure 1 Electrical Resistance-Temperature Curves

Nominal Resistance

Nominal resistance is the pre-specified resistance value at a given temperature. Most standards, including IEC-751, use zero as their reference point because it is easy to reproduce. The International Electrotechnical Commission (IEC) specifies the standard based on 100.00 Ohms at 0^{o}C, but other nominal resistances are quite common. Among the advantages that thin film technology has brought to the industry are small, economical elements with nominal resistances of 500, 1000, and even 2000
Ohms.

For some types of RTD's, there are also equations that give you the temperature from a given resistance. This information has made it possible for instrument manufacturers to provide standard readout and control devices that are compatible with some of the more widely accepted types of RTD's.

The heart of a RTD sensor is an element which is generally made of wire wond on a ceramic core. The element is encased in a metal sheath probe which provides good heat transfer as well as protection against moisture. The sheath is generally mades of stainless steel or some special metal alloy which can withstand high temperaures. RTD elements are usually made of platinum. Some RTDs have been made using nickel, copper ,iron or tungsten. The elemente`s resistance, usually calibrated at zero degrees C, will increase as the temperature rises. The RTD resistance increases by a factor of nearly two. If the element is placed in a wheatstone bridge circuit as shown in figure (2), the bridge would exhibit an imbalance as the element`s resistance increased with temperature.



Fig(2) RTD Sensor in Bridge Circuit

The RTD elements have the advantage that they can be used in high temperature applications. Although the RTD sensing element can be constructed of nickel, copper, tungsten or nickel-iron, the most useful metals platinum. Platinum can be highly refined. It resists contamination, it is mechanically and electrically stable and has a linear resistance versus temperature because of this linearity, and the meter calibration is directly correlated to the resistance changes.

PLATINUM RTD

The usual nominal resistance of platinum RTDs is 100ohms at 0° C. Unfortunately, standards are not identical worldwide, which presents a problem when a 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.

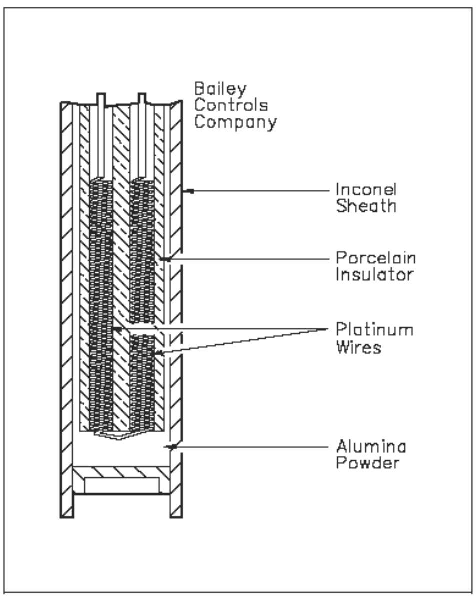
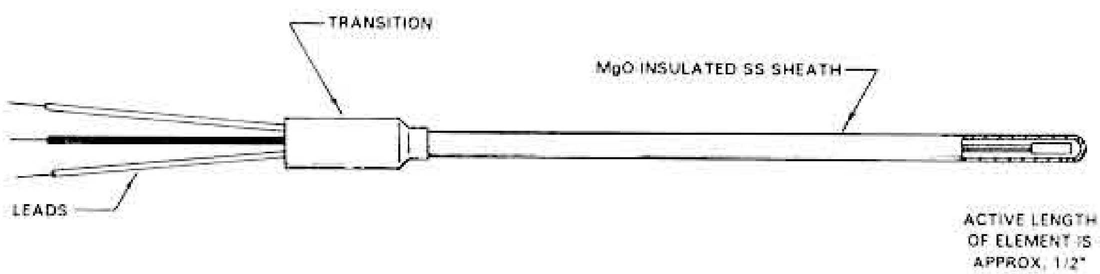


Figure 2 Internal Construction of a Typical RTD

GAYESCO offers platinum RTDs to all standards; the DIN and American standards the most available. Our normal tolerance is 0.1% of the reading. The following table delineates the most common standards.

ORGANIZATION	STANDARD	ALPHA: AVERAGE TEMP. COEFFICIENT OF RESISTANCE	NOMINAL RESISTANCE (OHMS) AT 0° C
BRITISH STANDARDS ASSOCIATION	B. S. 1904: 1984	0.003850	100
FACHNORMENAUSSCHUSS ELEKTROTECHNIK IN DEUTSCHEN NORMENAUSSCHUSS	DIN43760-1980	0.003850	100
U.S. DEPT. OF DEFENSE	MIL-T-24388	0.00392	100
INTERNATIONAL ELECTRONICAL COMMISSION	IEC 751: 1983	0.003850	100
JAPANESE STANDARD (JOINT INDUSTRIAL STANDARDS)	JIS C1604-1981	0.003916	100



Temperature measurements are performed almost exclusively with direct current the RTD is most often used in conjunction with external bridge circuitry. The degree of unbalance of a bridge becomes a measure of the environmental temperature in which the RTD probe is placed. The outputs of the meter at TP46 and TP47 can feed a bridge amplifier for more sensitive measurements.

The RTD in its commercial form is a temperature sensor of unequaled accuracy, stability and sensitivity. Performance approaching laboratory standards can be achieved in the most difficult environments.

RTD SPECIFICATIONS

Eight salient parameters must be addressed for every RTD application to ensure the desired performance. Many will be specified by the manufacturer of the instrument to which the RTD will be connected. If it is a custom circuit or special OEM application, the designers must make all the decisions. The four specifications dictated by the instrumentation or circuitry are: sensor material, temperature coefficient, nominal resistance, and, to some extent, wiring configuration. Sensor Material several metals are quite common for use in RTD's, and the purity of the metal as well as the element construction affects its characteristics. Platinum is by far the most popular due to its near linearity with temperature, wide temperature operating range, and superior long-term stability. Other materials are nickel, copper, balco (an iron-nickel alloy), tungsten, and iridium. Most of these are being replaced with platinum sensors, which are becoming more competitive in price through the wide use of thin film-type resistance elements that require only a very small amount of platinum as compared to a wire-wound element.

Temperature Coefficient

The temperature coefficient (TC) or ***alpha*** (α) of an RTD is a physical and electrical property of the metal alloy and the method by which the element was fabricated. The alpha describes the average resistance change per unit temperature from the ice point to the boiling point of water. (alpha is the percent change in resistance that takes place with each degree rise in temperature(C)). Various organizations have adopted a number of different α`s as their standards . The α value is multiplied by the resistance value at zero degrees, and then by the temperature rise plus the original resistance. This relationship is shown in equation (1).

$$\mathbf{R_{t2} = R_{t1}(1+ \alpha\, \Delta T)}$$

Where :

$\mathbf{R_{t2}}$ is the new resistance.

$\mathbf{R_{t1}}$ is the initial resistance at the reference temperature,t1.

$\mathbf{\Delta T}$ is the change in temperature,t2-t1.

Wiring Configuration

The wiring configuration is the last of those parameters typically specified by the instrument manufacturer, although the system designer does have some control based on the application. An RTD is inherently a 2-wire device, but lead wire resistance can drastically reduce the accuracy of the measurement by adding additional, uncompensated resistance into your system. Most applications therefore add a third wire to help the circuit compensate for lead wire resistance, and thus provide a truer indication of the measured temperature.

Four-wire RTD's provide slightly better compensation, but are generally found only in laboratory equipment and other areas where high accuracy is required.

Two other parameters are more application dependent the temperature range of the application; and, the accuracy.

Temperature Range

According to the ASTM, platinum RTD's can measure temperatures from -200^{o}C to 650^{o}C. (IEC says -200^{o}C to 850^{o}C).

You must consider the temperature limitations of all the materials involved, where they are applied, and the temperatures to which each will be exposed.

A few quick examples to illustrate this point:
TFE Teflon should not be used for wire insulation if it will be exposed to temperatures above 200^{o}C (250^{o}C for some).
Moisture proof seals are commonly made with various types of epoxy that generally have limits below that of the Teflon insulation.

Many wire insulating materials become brittle at subzero temperatures and therefore should not be used for cryogenic work. So state the intended temperature range right up front and let the applications engineer assist you, especially since it may affect the materials chosen for internal construction of the probe.

Accuracy

You are probably wondering why accuracy was not the first topic covered, because RTD's are generally known for their high degree of accuracy and it is typically one of the first specifications laid out. Well, the subject is not quite that simple, and it requires a bit of discussion. First, we must establish the difference between accuracy, precision, and repeatability. In the case of temperature, accuracy is commonly defined as how closely the sensor indicates the true temperature being measured, or in a more practical sense, how closely the resistance of the RTD matches the tabulated or calculated resistance of that type RTD at that given temperature.

Precision, on the other hand, is not concerned with how well the RTD's resistance matches the resistance from a look-up table, but rather with how well it matches the resistance of other RTD's subjected to that temperature. Precision generally refers to a group of sensors, and if the group has good precision at several temperatures, we can also say that they are well matched. This is important when interchangeability is a concern, as well as in the measurement of temperature gradients. Repeatability can best be described as the sensor's ability to reproduce its previous readings at a given temperature.

Our final two parameters are application dependent and vary from the specification of a bare resistance element to a large industrial assembly with thermowells, connection heads, and possibly field -mounted transmitters. We will discuss only the most basic areas: physical dimensions and size restrictions, and material compatibility.

Material Compatibility

Most people specifying RTD probes have to pay attention only to the chemical compatibility that will prevent corrosion. This is generally straightforward and guidelines can be taken from other materials used in the system in which the RTD will be installed. If the piping system is constructed of 316 S.S., then the probe probably should be also. But always check a corrosion guide for corrosion rates and material recommendations if you have the slightest doubt.

For applications involving thermowells, the thermowell will carry the burden of corrosion protection. However, be sure to protect the connecting wires and any terminals or plugs from possible corrosion caused by splash or corrosives in the atmosphere.

Applications of Resistance Temperature Detectors

- Air conditioning and refrigeration servicing
- Food Processing
- Stoves and grills
- Textile production
- Plastics processing
- Petrochemical processing
- Micro electronics
- Air, gas and liquid temperature measurement
- Exhaust gas temperature measurement

When to use Resistance Temperature Detectors

- When accuracy and stability are a requirement of the customer's specification.
- When accuracy must extend over a wide temperature range.
- When area, rather than point sensing improves control.
- When a high degree of standardisation is desirable.

Advantages of Resistance Temperature Detectors

- Linear over wide operating range
- Wide temperature operating range
- High temperature operating range
- Interchangeability over wide range
- Good stability at high temperature

Disadvantages of Resistance Temperature Detectors

- Low sensitivity
- Higher cost than thermocouples
- No point sensing
- Affected by shock and vibration · Requires three or four-wire operation

Resistance Temperature Detector or Thermocouple:

Both thermocouples and RTD's are useful sensors for determining process temperature. RTD's provide higher accuracy than thermocouples in their temperature range because platinum is a more stable material than are most thermocouple materials. RTD also uses standard instrumentation wire to connect to the measurement or control equipment.

Thermocouples are generally less expensive than RTDs, they are more durable in high vibration or mechanical shock applications and are usable to higher temperatures. Thermocouples can be made smaller in size than most RTD's so they can be formed to fit a particular application.

THERMOCOUPLE & RTD COMPARISON CHART
For Temperatures Under 900° F

Criteria	Thermocouple	Platinum RTD
Economics	Probe is cheaper	Probe is more expensive
	2-wire transitter 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
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 is not used

SUMMARY

There are quite a few things to be considered when specifying an RTD probe or even resistance elements. But it's just a matter of applying a bit of common sense and using information from the application environment to set down a clear set of requirements. And if there is something you are uncertain about, get your background information together and call that applications engineer.

Laboratory Experimentation

Test And Measurments:

The experimental circuit is located on panel SIP380-1 in setion G. figure 13-3 shows the ciruit diagram of the test circuit.

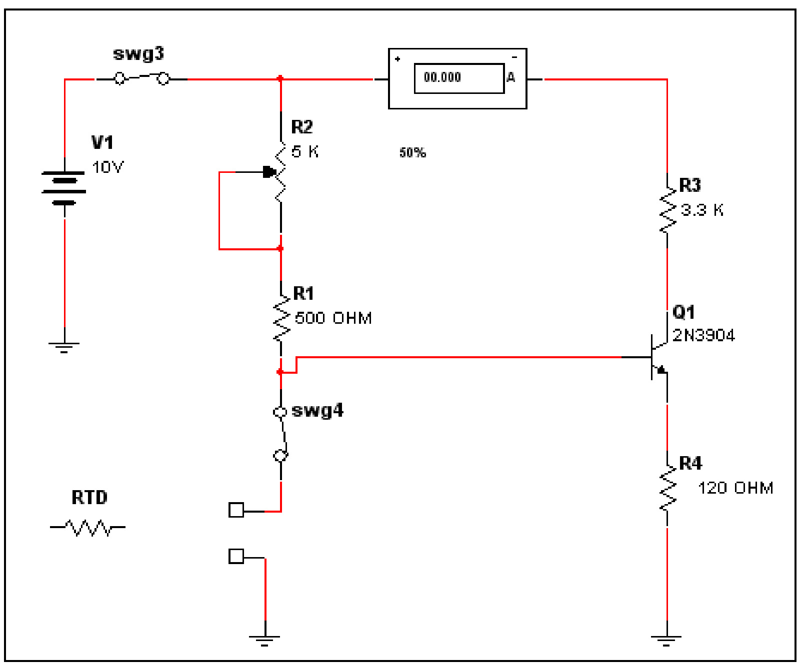


Figure 13-3 Thermistor /RTD Circuit

Materials Requied :

Master builder (S300B)
Insertion Panel with RTD sensor (SIP380-1)
Digital multimeter (DMM)
Thermometer ,0^{o} to 100^{o} C or 32^{o} to 212^{o} F
The experimental circuit is located on panel SIP380-1. Fig (2) shows the circuit diagram of the test circuit.

Experimental Procedures:

The RTD sensor is connected to the input of transistor amplifier. The current through the amplifier is initially adjusted to a low value and the current is then observed as the RTD sensor is heated.

1- With switch SWg-4 open, measure the resistance of the RTD sensor at room temperature. Measure across TP49 and TP50. Allow time for the resistance value to stabilize.

RTD = _______ Ω

2- Turn on the 10Ω heater resister by closing switch SWG-1. Allow 2 or 3 minutes for the heater to warm p. place the RTD element next to the heater and continue to measure the resistance of the RTD element. What is the value of the resistance after one minute of heating the element.
______ Ω

3-Allow the RTD sensor to cool again. Close switch SWg-4, which connects the RTD to the base of the amplifier. The sensor will be used to control the current through the amplifier. Adjust the power supply to 10VDC and set R1 fully clockwise (most resistance). Connect the 1 mA meter (note polarity) to TP51 and TP52. Close switch SWg-3 and adjust R1 so that the meter current (collector) reads near zero. With a DMM, measure the base bias voltage (Vb) between TP49 and TP50.

Vb = _____ VDC

4-When the sensor is again placed next to the heater resistor, the sensor`s resistance ***(increases/decreases)***and the voltage at the base***(increases/ decreases).***

5- Heat the RTD element for one minute and record the folowing:
Collector (meter) current, Ic=______mA
Base voltage, Vb=_____VDC
Collector voltage, Vc=_____VDC

6-DC gain is determined from:

$$A_{DC} = \frac{\Delta Vc}{\Delta Vb}$$

Where **ΔV** is the change in voltage due to a rise in temperature. Therefore, A_{DC} =________ .

7-Did the measurements verify that a rise in temperature causes an increase in the resistance of the RTD sensor ______.

8- Use R of room temperature above 0^o ______ **^{o}C.**

9-What is the temperature next to the heater coil.
Use the results from steps 1 and 2 and an α of 0.00392 to calculate this temperature.
_______ **^{o}C**

10-The temperature difference between the heater and room temperature is
_________ **^{o}C**

Review Quistions:

1. How does the RTD differ from the thermistor and the thermocouple.

2-Is the temperature coefficient of an RTD positive or negative.

3- Assume that at 22 ^{o}C, the alpha of a 100Ω RTD sensor is 0.00392 and the RTD is placed in an environment of 72 ^{o}C. What is its new resistance o show your calculations.

4- What is the reference temperature which the resistance of most RTDs is specified.

5- Discuss the meaning of the term *alpha* as applied to a RTD sensor.

6- Why does the 1.0 mA meter in the RTD controlled amplifier read in a positive direction.

7- How could the experimental circuit be used to measure an unknown temperature.