Phoenix Thermal Supply

What is the Difference Between a 2, 3, and 4 Wire RTD?

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RTD circuits work by sending a known amount of current through an RTD sensor and then measuring the voltage drop across that resistor at the given temperature. Because every Pt100 element in the circuit containing the sensing element—including the lead wires, connectors and the measuring instrument itself—will introduce additional resistance into the circuit, it's important to be able to factor out the unwanted resistances when measuring the voltage drop across the RTD's sensing element.

How the circuit is configured determines how accurately the sensor's resistance can be calculated, and how much the temperature reading may be distorted by extraneous resistance in the circuit. Since the lead wire used between the resistance element and the measuring instrument has a resistance itself, we must also supply a means of compensating for this inaccuracy.

Wire Materials

When specifying the RTD wire materials, care should be taken to select the right lead wires for the temperature and environment the sensor will be exposed to in service. When selecting lead wires, temperature is by far the primary consideration, however, physical properties such as abrasion resistance and water submersion characteristics can also be important. The three most popular constructions are:

- PVC Insulated Probes offer a temperature range of -40 to 105°C, with good Abrasion Resistance and applicable for Water Submersion.
- PFA Insulated pt100 Probes offer a temperature range of -267 to 260°C with Excellent Abrasion Resistance. They are also great for Water Submersion Applications.
- Although Fiberglass Insulated pt100 Probes offer a higher temperature range of -73 to 482°C, its performance under abrasion or water submersion is considered to be not as effective.

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Resistance to Temperature Conversion

The RTD is a more linear device than the thermocouple, but it still requires curve-fitting. The Callendar-Van Dusen equation has been used for years to approximate the RTD curve:

$$R_g = R_3 \left(\frac{V_s - 2V_o}{V_S + 2V_o}\right) - R_L \left(\frac{4V_o}{Vs + 2V_o}\right)$$

Where:

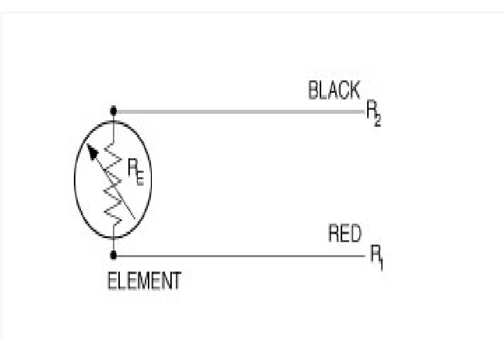
R_T = Resistance at Temperature T
R_o = Resistance at T = 0ºC
α = Temperature coefficient at T = 0ºC ((typically +0.00392Ω/Ω/ºC))
δ = 1.49 (typical value for .00392 platinum)
β = 0 T > 0 0. 11 (typical) T < 0

The exact values for coefficients α , β, and δ are determined by testing the RTD at four temperatures and solving the resultant equations. This familiar equation was replaced in 1968 by a 20th order polynomial in order to provide a more accurate curve fit. The plot of this equation shows the RTD to be a more linear device than the thermocouple.

RTD wiring configurations

There are three types of wire configurations, 2 wire, 3 wire, and 4 wire, that are commonly used in RTD sensing circuits. A 2-wire configuration with a compensating loop is also an option.

2 wire RTD connections



The 2 wire RTD configuration is the simplest among RTD circuit designs. In this serial configuration, a single lead wire connects each end of the RTD element to the monitoring device. Because the resistance calculated for the circuit includes the resistance in the lead wires and connectors as well as the resistance in the RTD element, the result will always contain some degree of error.

The circle represents the resistance element boundaries to the point of calibration. 3- or 4-wire configuration must be extended from the point of calibration so that all uncalibrated resistances are compensated.

The resistance RE is taken from the resistance element and is the value that will supply us with an accurate temperature measurement. Unfortunately, when we take our resistance measurement, the instrument will indicate RTOTAL:

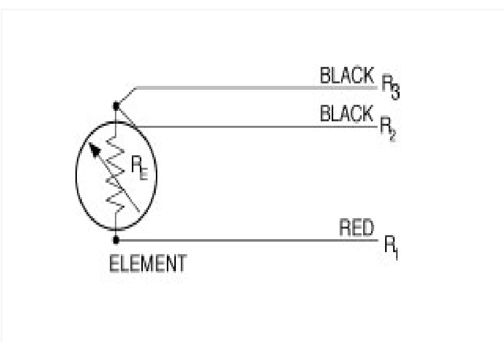
Where

RT = R1 + R2 + RE

This will produce a temperature readout higher than that actually being measured. Many systems can be calibrated to eliminate this. Most RTD’s incorporate a third wire with resistance R3. This wire will be connected to one side of the resistance element along with lead 2.

Although the use of high-quality test leads and connectors can reduce this error, it is impossible to eliminate it entirely A larger gauge wire with less resistance will minimize the error. A 2 wire RTD configuration is the most useful with high-resistance sensors or in applications where a great deal of accuracy is not required.

3 wire RTD connections



The 3 wire RTD configuration is the most commonly used RTD circuit design and can be seen in industrial process and monitoring applications. In this configuration, two wires link the sensing element to the monitoring device on one side of the sensing element, and one links it on its other side.

If three identical type wires are used and their lengths are equal, then R1 = R2 = R3. By measuring the resistance through leads 1, 2 and the resistance element, a total system resistance is measured (R1 + R2 + RE).

If the resistance is also measured through leads 2 and 3 (R2 + R3), we obtain the resistance of just the lead wires, and since all lead wire resistances are equal, subtracting this value (R2 + R3) from the total system resistance (R1 + R2 + RE) leaves us with just RE, and an accurate temperature measurement has been made.

Because this is an averaged result, the measurement will be accurate only if all three connecting wires have the same resistance.

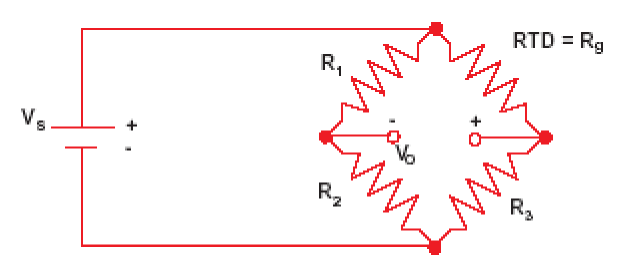


Figure 43

3-Wire Bridge Measurement Errors

If we know V_S and V_O, we can find R_g and then solve for temperature. The unbalance voltage V_O of a bridge built with $R_1 = R_2$ is:

$$V_O = V_S\left(\frac{R_3}{R_3 + R_g}\right) - V_S\left(\frac{1}{2}\right)$$

If $R_g = R_3$, $V_O = 0$ and the bridge is balanced. This can be done manually, but if we don't want to do a manual bridge balance, we can just solve for R_g in terms of V_O.

This expression assumes the lead resistance is zero. If R_g is located some distance from the bridge in a 3-wire configuration, the lead resistance RL will appear in series with both R_g and R_3.

Again we solve for R_g.

$$R_g = R_3\left(\frac{V_S - 2V_O}{V_S + 2V_O}\right)$$

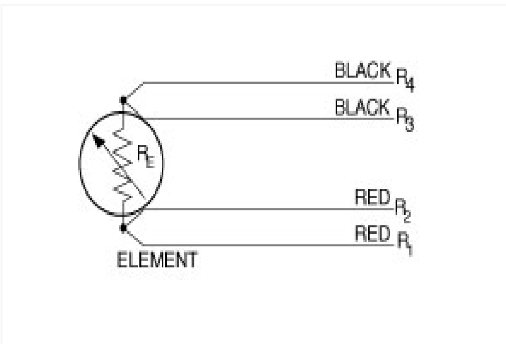
The error term will be small if V_o is small, i.e., the bridge is close to balance. This circuit works well with devices like strain gauges, which change resistance value by only a few percent, but an RTD changes resistance dramatically with temperature. Assume the RTD resistance is 200 ohms and the bridge is designed for 100 ohms:

Since we don't know the value of R_L, we must use equation (a), so we get:

The correct answer is of course 200 ohms. That's a temperature error of about 2.5ºC.

Unless you can actually measure the resistance of RL or balance the bridge, the basic 3-wire technique is not an accurate method for measuring absolute temperature with an RTD. A better approach is to use a 4-wire technique.

4 wire RTD connections



This configuration is the most complex and thus the most time-consuming and expensive to install, but it produces the most accurate results.

The bridge output voltage is an indirect indication of the RTD resistance. The bridge requires four connection wires, an external source, and three resistors that have a zero temperature coefficient. To avoid subjecting the three bridge-completion resistors to the same temperature as the RTD sensor, the RTD is separated from the bridge by a pair of extension wires:

These extension wires recreate the problem that we had initially: The impedance of the extension wires affects the temperature reading. This effect can be minimized by using a three-wire bridge configuration:

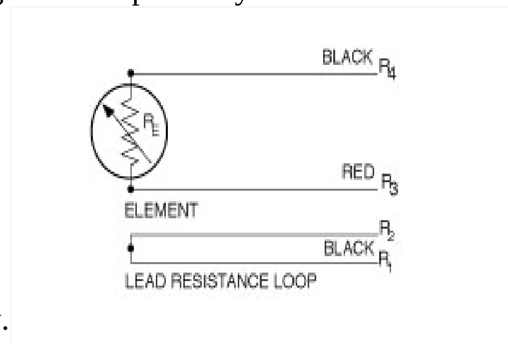
In a 4-wire RTD configuration, two wires link the sensing element to the monitoring devise on both sides of the sensing element. One set of wires delivers the current used for measurement, and the other set measures the voltage drop over the resistor.

With the 4-wire configuration, the instrument will pass a constant current (I) through the outer leads, 1 and 4.

The Wheatstone bridge creates a non-linear relationship between resistance change and bridge output voltage change. This compounds the already non-linear temperature-resistance characteristic of the RTD by requiring an additional equation to convert bridge output voltage to equivalent RTD impedance.

The voltage drop is measured across the inner leads, 2 and 3. So from V = IR we learn the resistance of the element alone, with no effect from the lead wire resistance. This offers an advantage over 3-wire configurations only if dissimilar lead wires are used, and this is rarely the case.

This 4 wire bridge design fully compensates for all resistance found in the lead wires and the connectors between them. A 4 wire RTD configuration is primarily used in laboratories and other settings where great accuracy is necessary.



2-wire configuration with a closed loop

Still another configuration, now rare, is a standard 2-wire configuration with a closed loop of wire alongside (Figure 5). This functions the same as the 3-wire configuration, but uses an extra wire to do so. A separate pair of wires is provided as a loop to provide compensation for lead resistance and ambient changes in lead resistance.**Our engineers are factory trained on all applications and will help with any questions that you have**