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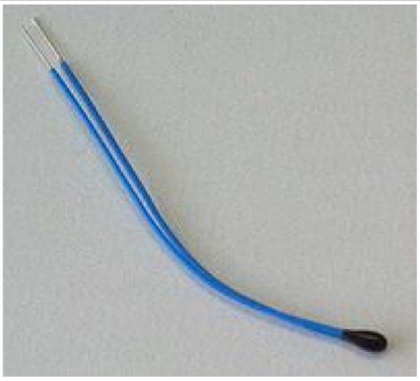
Thermistor

A **thermistor** is a type of resistor whose resistance is dependent on temperature, more so than in standard resistors. The word is a portmanteau of *thermal* and *resistor*. Thermistors are widely used as inrush current limiters, temperature sensors (negative temperature coefficient or **NTC** type typically), self-resetting overcurrent protectors, and self-regulating heating elements (positive temperature coefficient or **PTC** type typically).

Thermistor



Negative temperature coefficient (NTC) thermistor, bead type, insulated wires

Type	Passive
Working principle	Electric resistance

Electronic symbol

Thermistor symbol

Thermistors are of two opposite fundamental types:

- With **NTC** thermistors, resistance ***decreases*** as temperature rises. An NTC is commonly used as a temperature sensor, or in series with a circuit as an inrush current limiter.
- With **PTC** thermistors, resistance ***increases*** as temperature rises. PTC thermistors are commonly installed in series with a circuit, and used to protect against *overcurrent* conditions, as resettable fuses.

Thermistors differ from resistance temperature detectors (RTDs) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The thermistors are in the form of beads, rods and discs but RTDs are in different shapes and sizes. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a greater precision within a limited temperature range, typically −90 °C to 130 °C.[1]

Contents

Basic operation

Assuming, as a first-order approximation, that the relationship between resistance and temperature is linear, then:

$$\Delta R = k \Delta T$$

where

ΔR, change in resistance
ΔT, change in temperature
k, first-order temperature coefficient of resistance

Thermistors can be classified into two types, depending on the classification of k. If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (**PTC**) thermistor, or **posistor**. If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (**NTC**) thermistor. Resistors that are not thermistors are designed to have a k as close to 0 as possible, so that their resistance remains nearly constant over a wide temperature range.

Instead of the temperature coefficient k, sometimes the *temperature coefficient of resistance* α_T (alpha sub T) is used. It is defined as[2]

$$\alpha_T = \frac{1}{R(T)} \frac{dR}{dT}.$$

This α_T coefficient should not be confused with the a parameter below.

Steinhart–Hart equation

In practice, the linear approximation (above) works only over a small temperature range. For accurate temperature measurements, the resistance/temperature curve of the device must be described in more detail. The Steinhart–Hart equation is a widely used third-order approximation:

$$\frac{1}{T} = a + b\,\ln(R) + c\,(\ln(R))^3$$

where a, b and c are called the Steinhart–Hart parameters, and must be specified for each device. T is the absolute temperature and R is the resistance. To give resistance as a function of temperature, the above can be rearranged into:

$$R = \exp\left[\left(x - \frac{1}{2}y\right)^{\frac{1}{3}} - \left(x + \frac{1}{2}y\right)^{\frac{1}{3}}\right]$$

where

$$y = \frac{1}{c}\left(a - \frac{1}{T}\right)$$
$$x = \sqrt{\left(\frac{b}{3c}\right)^3 + \left(\frac{y}{2}\right)^2}$$

The error in the Steinhart–Hart equation is generally less than 0.02 °C in the measurement of temperature over a 200 °C range.[3] As an example, typical values for a thermistor with a resistance of 3 kΩ at room temperature (25 °C = 298.15 K) are:

$$a = 1.40 \times 10^{-3}$$
$$b = 2.37 \times 10^{-4}$$
$$c = 9.90 \times 10^{-8}$$

B or *β* parameter equation

NTC thermistors can also be characterised with the B (or β) parameter equation, which is essentially the Steinhart–Hart equation with $a = (1/T_0) - (1/B)\ln(R_0)$, $b = 1/B$ and $c = 0$,

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B}\ln\left(\frac{R}{R_0}\right),$$

where the temperatures are in kelvins, and R_0 is the resistance at temperature T_0 (25 °C = 298.15 K). Solving for R yields:

$$R = R_0 e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

or, alternatively,

$$R = r_\infty e^{B/T}$$

where $r_\infty = R_0 e^{-B/T_0}$.

This can be solved for the temperature:

$$T = \frac{B}{\ln\left(R/r_\infty\right)}$$

The B-parameter equation can also be written as $\ln R = B/T + \ln r_\infty$. This can be used to convert the function of resistance vs. temperature of a thermistor into a linear function of $\ln R$ vs. $1/T$. The average slope of this function will then yield an estimate of the value of the *B* parameter.

Conduction model

NTC (negative temperature coefficient)

Many NTC thermistors are made from a pressed disc, rod, plate, bead or cast chip of semiconducting material such as sintered metal oxides. They work because raising the temperature of a semiconductor increases the number of active charge carriers - it promotes them into the *conduction band*. The more charge carriers that are available, the more current a material can conduct. In certain materials like ferric oxide (Fe_2O_3) with titanium (Ti) doping an *n-type* semiconductor is formed and the charge carriers are electrons. In materials such as nickel oxide (NiO) with lithium (Li) doping a *p-type* semiconductor is created where holes are the charge carriers.[4]

A failed (blown) NTC thermistor that worked as an inrush current limiter in a switched-mode power supply. The most likely cause of failure was overload caused by engineering failure (the part was constantly subjected to a higher load than what it was designed for)

This is described in the formula:

$$I = n \cdot A \cdot v \cdot e$$

I = electric current (amperes)
n = density of charge carriers (count/m^3)
A = cross-sectional area of the material (m^2)
v = drift velocity of electrons (m/s)
e = charge of an electron ($e = 1.602 \times 10^{-19}$ coulomb)

Over large changes in temperature, calibration is necessary. Over small changes in temperature, if the right semiconductor is used, the resistance of the material is linearly proportional to the temperature. There are many different semiconducting thermistors with a range from about 0.01 kelvin to 2,000 kelvins (−273.14 °C to 1,700 °C).

The IEC standard symbol for a NTC thermistor includes a "-t°" under the rectangle.[5]

PTC (positive temperature coefficient)

Most PTC thermistors are made from doped polycrystalline ceramic (containing barium titanate ($BaTiO_3$) and other compounds) which have the property that their resistance rises suddenly at a certain critical temperature. Barium titanate is ferroelectric and its dielectric constant varies with temperature. Below the Curie point temperature, the high dielectric constant prevents the formation of potential barriers between the crystal grains, leading to a low resistance. In this region the device has a small negative temperature coefficient. At the Curie point temperature, the dielectric constant drops sufficiently to allow the formation of potential barriers at the grain boundaries, and the resistance increases sharply with temperature. At even higher temperatures, the material reverts to NTC behaviour.

Another type of thermistor is a **silistor**, a thermally sensitive silicon resistor. Silistors employ silicon as the semiconductive component material. Unlike ceramic PTC thermistors, silistors have an almost linear resistance-temperature characteristic.[6]

Barium titanate thermistors can be used as self-controlled heaters; for a given voltage, the ceramic will heat to a certain temperature, but the power used will depend on the heat loss from the ceramic.

The dynamics of PTC thermistors being powered also is extremely useful. When first connected to a voltage source, a large current corresponding to the low, cold, resistance flows, but as the thermistor self-heats, the current is reduced until a limiting current (and corresponding peak device temperature) is reached. The current-limiting effect can replace fuses. They are also used in the degaussing circuits of many CRT monitors and televisions where the degaussing coil only has to be connected in series with an appropriately chosen thermistor; a particular advantage is that the current decrease is smooth, producing optimum degausing effect. Improved degaussing circuits have auxiliary heating elements to heat the thermistor further (and reduce the final current) or timed relays to disconnect the degaussing circuit entirely after it has operated.

Another type of PTC thermistor is the polymer PTC, which is sold under brand names such as "Polyswitch" "Semifuse", and "Multifuse". This consists of plastic with carbon grains embedded in it. When the plastic is cool, the carbon grains are all in contact with each other, forming a conductive path through the device. When the plastic heats up, it expands, forcing the carbon grains apart, and causing the resistance of the device to rise, which then causes increased heating and rapid resistance increase. Like the $BaTiO_3$ thermistor, this device has a highly nonlinear resistance/temperature response useful for thermal or circuit control, not for temperature measurement. Besides circuit elements used to limit current, self-limiting heaters can be made in the form of wires or strips, useful for heat tracing. PTC thermistors 'latch' into a hot / high resistance state: once hot, they stay in that high resistance state, until cooled. In fact, Neil A Downie showed how you can use the effect as a simple latch/memory circuit, the effect being enhanced by using two PTC thermistors in series, with thermistor A cool, thermistor B hot, or vice versa.[7]

The IEC standard symbol for a PTC thermistor includes a "+t°" under the rectangle.[8]

Self-heating effects

When a current flows through a thermistor, it will generate heat which will raise the temperature of the thermistor above that of its environment. If the thermistor is being used to measure the temperature of the environment, this electrical heating may introduce a significant error if a correction is not made. Alternatively, this effect itself can be exploited. It can, for example, make a sensitive air-flow device employed in a sailplane rate-of-climb instrument, the electronic variometer, or serve as a timer for a relay as was formerly done in telephone exchanges.

The electrical power input to the thermistor is just:

$$P_E = IV$$

where *I* is current and *V* is the voltage drop across the thermistor. This power is converted to heat, and this heat energy is transferred to the surrounding environment. The rate of transfer is well described by Newton's law of cooling:

$$P_T = K(T(R) - T_0)$$

where *T(R)* is the temperature of the thermistor as a function of its resistance *R*, T_0 is the temperature of the surroundings, and *K* is the **dissipation constant**, usually expressed in units of milliwatts per degree Celsius. At equilibrium, the two rates must be equal.

$$P_E = P_T$$

The current and voltage across the thermistor will depend on the particular circuit configuration. As a simple example, if the voltage across the thermistor is held fixed, then by Ohm's Law we have $I = V/R$ and the equilibrium equation can be solved for the ambient temperature as a function of the measured resistance of the thermistor:

$$T_0 = T(R) - \frac{V^2}{KR}$$

The dissipation constant is a measure of the thermal connection of the thermistor to its surroundings. It is generally given for the thermistor in still air, and in well-stirred oil. Typical values for a small glass bead thermistor are 1.5 mW/°C in still air and 6.0 mW/°C in stirred oil. If the temperature of the environment is known beforehand, then a thermistor may be used to measure the value of the dissipation constant. For example, the thermistor may be used as a flow rate sensor, since the dissipation constant increases with the rate of flow of a fluid past the thermistor.

The power dissipated in a thermistor is typically maintained at a very low level to ensure insignificant temperature measurement error due to self heating. However, some thermistor applications depend upon significant "self heating" to raise the body temperature of the thermistor well above the ambient temperature so the sensor then detects even subtle changes in the thermal conductivity of the environment. Some of these applications include liquid level detection, liquid flow measurement and air flow measurement.[2]

Applications

PTC

- As current-limiting devices for circuit protection, as replacements for fuses. Current through the device causes a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings, the device heats up, causing its resistance to increase. This creates a self-reinforcing effect that drives the resistance upwards, therefore limiting the current.
- As timers in the degaussing coil circuit of most CRT displays. When the display unit is initially switched on, current flows through the thermistor and degaussing coil. The coil and thermistor are intentionally sized so that the current flow will heat the thermistor to the point that the degaussing coil shuts off in under a second. For effective degaussing, it is necessary that the magnitude of the alternating magnetic field produced by the degaussing coil decreases smoothly and continuously, rather than sharply switching off or decreasing in steps; the PTC thermistor accomplishes this naturally as it heats up. A degaussing circuit using a PTC thermistor is simple, reliable (for its simplicity), and inexpensive.
- As heater in automotive industry to provide additional heat inside cabin with diesel engine or to heat diesel in cold climatic conditions before engine injection.
- In temperature compensated synthesizer voltage controlled oscillators.[9]
- In lithium battery protection circuits.[10]
- In an electrically actuated Wax motor to provide the heat necessary to expand the wax.
- Many electric motors and dry type power transformers incorporate PTC thermistors in their windings. When used in conjunction with a monitoring relay they provide overtemperature protection to prevent insulation damage. The equipment manufacturer selects a thermistor with a highly non-linear response curve where resistance increases dramatically at the maximum allowable winding temperature, causing the relay to operate.

NTC

- As a resistance thermometer for low-temperature measurements of the order of 10 K.
- As an inrush current limiter device in power supply circuits, they present a higher

resistance initially, which prevents large currents from flowing at turn-on, and then heat up and become much lower resistance to allow higher current flow during normal operation. These thermistors are usually much larger than measuring type thermistors, and are purposely designed for this application.[11]

- As sensors in automotive applications to monitor fluid temperatures like the engine coolant, cabin air, external air or engine oil temperature, and feed the relative readings to control units like the ECU and to the dashboard.
- To monitor the temperature of an incubator.
- Thermistors are also commonly used in modern digital thermostats and to monitor the temperature of battery packs while charging.
- Thermistors are often used in the hot ends of 3D printers; they monitor the heat produced and allow the printer's control circuitry to keep a constant temperature for melting the plastic filament.
- In the food handling and processing industry, especially for food storage systems and food preparation. Maintaining the correct temperature is critical to prevent foodborne illness.
- Throughout the consumer appliance industry for measuring temperature. Toasters, coffee makers, refrigerators, freezers, hair dryers, etc. all rely on thermistors for proper temperature control.
- NTC thermistors come in bare and lugged forms, the former is for point sensing to achieve high accuracy for specific points, such as laser diode die, etc.[12]
- For measurement of temperature profile inside the sealed cavity of a convective (thermal) inertial sensor[13].

History

The first NTC thermistor was discovered in 1833 by Michael Faraday, who reported on the semiconducting behavior of silver sulfide. Faraday noticed that the resistance of silver sulfide decreased dramatically as temperature increased. (This was also the first documented observation of a semiconducting material.)[14]

Because early thermistors were difficult to produce and applications for the technology were limited, commercial production of thermistors did not begin until the 1930s.[15] A commercially viable thermistor was invented by Samuel Ruben in 1930.[16]

See also

- Iron-hydrogen resistor
- Thermocouple

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External links

- The thermistor at bucknell.edu (http://www.facstaff.bucknell.edu/mastascu/eLessonsHTML/Sensors/TempR.html)
- Software for thermistor calculation at Sourceforge (http://thermistor.sourceforge.net/)
- "Thermistors & Thermocouples:Matching the Tool to the Task in Thermal Validation" (http://img.en25.com/Web/Vaisala/JVT%20KBull%20Article_final%20pdf.pdf) - Journal of Validation Technology