NTC Thermistors
Engineering Notes

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Introduction

A negative temperature coefficient (NTC) thermistor is a two terminal solid state electronic component that exhibits a large, predictable change in resistance corresponding to changes in absolute body temperature. This change in body temperature of the thermistor can be brought about either externally via a change in ambient temperature or internally by heat resulting from current passing through the device or by a combination of these effects.

NTC thermistors are manufactured using metallic oxides of manganese, nickel, cobalt, copper, iron and other metals. They are fabricated using a mixture of two or more metallic oxides and a binder material and are then pressed into the desired configuration. The resulting material is then sintered at elevated temperatures. By varying the types of oxides, the sintering time and temperature as well as the atmosphere, a wide variety of curves and resistance values can be manufactured.

Thermistor Terminology

Thermistors exhibit a large negative change in resistance with respect to temperature, on the order of -3%/°C to -6%/°C at 25°C. This relationship between resistance and temperature follows an approximately exponential-type curve as shown below. A few parameters will help to describe the curve and how it changes over temperature.
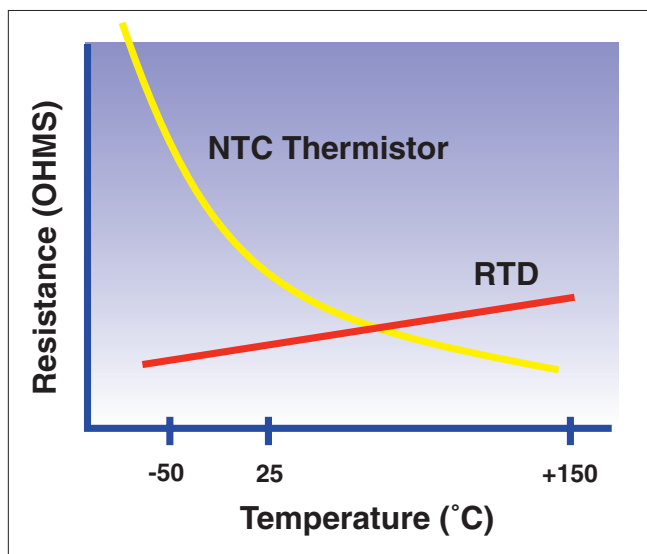

Figure 20: Resistance vs. Temperature graph for an NTC Thermistor vs. an RTD

Resistance at 25°C (R$_{25}$)

The most common temperature used to measure the thermistor resistance and the one temperature that is most often used to reference the resistance value of the thermistor is 25°C. For NTC thermistors, this value can vary from less than 100Ω to greater than 1MegΩ. The value at 25°C is normally measured in a temperature controlled bath where very low power is used to measure the resistance value. When a resistance value for a thermistor is mentioned, it is the value at 25°C that is usually being used.

Temperature Coefficient of Resistance (α)

One way to describe the curve of an NTC thermistor is to measure the slope of the resistance versus temperature (R/T) curve at one temperature. By definition, the coefficient of resistance is given by:

$$\alpha = \frac{1}{R} * \frac{dR}{dT}$$

Where:

T = Temperature in °C or K
R = Resistance at Temp T

The temperature coefficient is expressed in ohms/ohms/°C or more commonly %/°C.

As can be seen from Figure 20, the steepest portion of the NTC curve is at colder temperatures. Depending upon the type of NTC material, the temperature coefficient at -40°C can be as high as -8%/°C. The flattest portion of the curve occurs at higher temperatures where, at temperatures of 300°C, α can be less than 1%/°C.

The temperature coefficient is one method that can be used to compare the relative steepness of NTC curves. It is important that the temperature coefficient be compared at the same temperature because, as was noted previously, α varies widely over the operating temperature range.

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Resistance Ratio (Slope)

The resistance ratio, or slope, for thermistors is defined as the ratio of resistance at one temperature to the resistance at a second higher temperature. The resistance ratio is one method of describing the NTC curve. It is sometime used to compare the relative steepness of two curves. There is no industry standard for the two temperatures that are used to calculate the ratio, although some common temperature ranges are:

$$\frac{R@0°C}{R@50°C} \quad \frac{R@25°C}{R@50°C} \quad \frac{R@25°C}{R@85°C}$$

The value obtained by taking the resistance ratio at different temperatures will vary greatly depending upon the temperatures used. Therefore, resistance ratios cannot be used to compare thermistor curves unless the same temperature ranges are used. For example, for SS&C Curve "Z", the following ratios are obtained:

$$\frac{R@0°C}{R@50°C} = \frac{3.265}{0.3601} = 9.07$$

$$\frac{R@25°C}{R@50°C} = \frac{1.000}{0.3601} = 2.78$$

$$\frac{R@25°C}{R@85°C} = \frac{1.000}{0.1071} = 9.34$$

Beta value (β)

A simple approximation for the relationship between the resistance and temperature for a NTC thermistor is to use an exponential approximation between the two. This approximation is based on simple curve fitting to experimental data and uses two points on a curve to determine the value of β. The equation relating resistance to temperature using β is:

$$R = Ae^{(\beta/T)}$$

Where:
R = thermistor resistance at temp T
A = constant of equation
β = beta, the material constant
T = thermistor temperature (K)

To calculate Beta for any given temperature range, the following formula applies:

$$\beta = \left(\frac{T_1 * T_2}{T_2 - T_1}\right) \ln \frac{R_1}{R_2}$$

β can be used to compare the relative steepness of NTC thermistor curves. However, as with resistance ratios, the value of β will vary depending upon the temperatures used to calculate the value, although not to the extent that resistance ratio does. For example, to calculate β for the temperature range of 0°C to 50°C for SS&C curve "Z":

$T_1 = 0°C + 273.15°C = 273.15K$
$T_2 = 50°C + 273.15°C = 323.15K$
$R_1 = 3.265$
$R_2 = 0.3601$

$$\beta = \left(\frac{323.15 * 273.15}{323.15 - 273.15}\right) * \ln \frac{3.265}{0.3601} = 3892K$$

This value of β would be referenced as $\beta_{0°C/50°C}$. Using other temperatures to calculate β for curve "Z" would yield the following results:

$\beta_{25°C/50°C} = 3936K$
$\beta_{25°C/85°C} = 3976K$

As you can see, it is important to know what temperatures were used to calculate the value of β before it is used to compare thermistor curves. β can be used to calculate the resistance of the curve at other temperatures within the range that β was calculated once the constant A is determined. However, the accuracy of this equation is only approximately ±0.5°C over a 50°C span.

Steinhart-Hart Thermistor equation

The Steinhart-Hart equation is an empirically derived polynomial formula which best represents the resistance versus temperature relationship of NTC thermistors. The Steinhart-Hart equation is the best method used to describe the RvT relationship and is accurate over a much wider range of temperature than is β. To solve for temperature when resistance is known, yields the following form of the equation:

$$1/T = a + b(LnR) + c(LnR)^3$$

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Where:
  T = temperature in Kelvins (K = ˚C + 273.15)
  a, b and c are equation constants
  R = resistance in Ω at temp T

To solve for resistance when the temperature is known, the form of the equation is:

$$R=e^{\left[\left(-\frac{\chi}{2}+\left(\frac{\chi^2}{4}+\frac{\psi^3}{27}\right)^{1/2}\right)^{1/3}+\left(-\frac{\chi}{2}-\left(\frac{\chi^2}{4}+\frac{\psi^3}{27}\right)^{1/2}\right)^{1/3}\right]}$$

Where:

$$\chi = \frac{a-1/T}{c} \qquad \psi = \frac{b}{c}$$

The a, b and c constants can be calculated for either a thermistor material or for individual values of thermistors within a material type. To solve for the constants, three sets of data must be used. Normally, for a temperature range, values at the low end, middle and high end are used to calculate the constants. This will ensure the best fit for the equation over the range. Using the Steinhart-Hart equation allows for an accuracy as good as ±0.001˚C over a 100˚C temperature span. Print outs that contain resistance versus temperature data for individual parts is available by contacting SS&C.

Thermistor tolerance and temperature accuracy
There are two factors to consider when discussing thermistors and their ability to measure temperature. The first is resistance tolerance and this is defined as the amount of resistance that any part will vary from its nominal value. The tolerance on the resistance at any temperature is the sum of:
a) the closest tolerance at any specified temperature
b) the additional tolerance due to deviation from the nominal curve for the material

In any application where the thermistor is to be used to measure temperature it is more appropriate to discuss the temperature accuracy for the device. The accuracy can be calculated if the resistance tolerance and α are known.

There are two generally accepted methods of describing the tolerance or accuracy of a thermistor. The first is *point*

matched. This describes a thermistor that has its tightest resistance tolerance at one temperature, the reference temperature, which is normally 25˚C. At temperatures below and above the reference temperature the resistance tolerance will become larger due to the uncertainty in the material curve. The other type of thermistor tolerance is known as *curve matched* or *interchangeable*. These thermistors are normally defined to have a certain accuracy over a range, typically ±0.2˚C from 0˚C to 70˚C.

A simple equation is used to describe the relationship between resistance tolerance and temperature accuracy. When one is known the other can be calculated.

$$\text{Accy}= \frac{\text{Res Tol}}{\alpha} \quad \text{or} \quad \text{Res Tol} = \text{Accy} * \alpha$$

For example, for SS&C part number A1004Z-2, the resistance tolerance is ±2% @ 25˚C. Looking at the data for curve "Z" shows that the α at 25˚C is 4.4 %/˚C. Therefore, the accuracy at 25˚C can be calculated to be (±2%/4.4%/˚C) = ±0.45˚C.

Similarly, for SS&C part number A1004Z-C3, the temperature accuracy is expressed as ±0.2˚C from 0˚C to 70˚C. To calculate the resistance tolerance at 25˚C divide the temperature accuracy at the temperature by the α at that temperature. For 25˚C, the resistance tolerance would be (±0.2˚C * 4.4%/˚C) = ±0.88%.

In the data section for NTC thermistors, SS&C also provides the curve deviation for parts that are point matched at 25˚C. Using this information and the value of α, allows for the temperature accuracy to be calculated at any temperature. For example for curve "Z" at 50˚C for SS&C part number A1004Z-2, the resistance tolerance at 25˚C is ±2%. The deviation due to the curve uncertainty is listed as ±1.2%. Therefore, the total resistance tolerance would be:

$$(\pm2\%) + (\pm1.2\%) = \pm 3.2\% @ 50˚C$$

The α at 50˚C for this material is listed as -3.8%/˚C. Therefore, to calculate the temperature accuracy at 50˚C for A1004Z-2:

$$(\pm3.2\%) / (-3.8\%/˚C) = \pm0.84˚C$$

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The α at 50˚C for this material is listed as -3.8%/˚C. An example of how the accuracy of a thermistor changes with respect to temperature can be seen in the following graph.
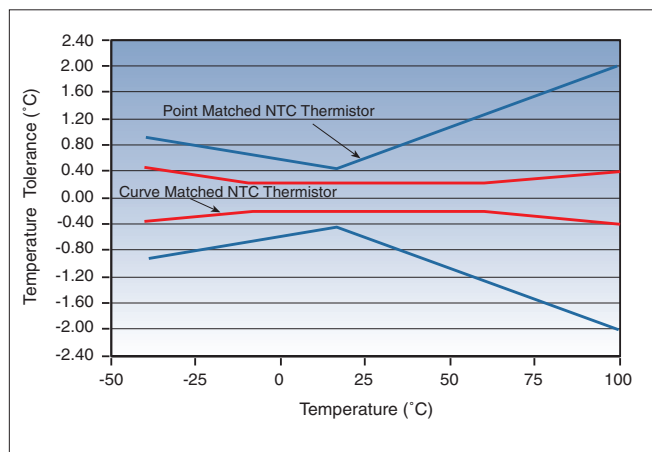

Figure 21: Temperature Tolerance of NTC Thermistors (Point Matched vs Interchangeable)

NTC Thermistor self-heated parameters

Self-heating occurs in a thermistor when current passing through the device is such that the internal heat generated is sufficient to raise the thermistor body temperature above that of its environment. For temperature sensing applications, it is not desirable to self-heat the thermistor to any extent. Other NTC thermistor applications utilize the self heated characteristics inherent to the parts. The ability of a thermistor to dissipate power is a function of the size of the part, its geometry, lead material and size, method of mounting and any other factor that would contribute to the ability of the part to dissipate heat.

Dissipation Factor (δ)

The dissipation factor, δ, defines the relationship between the applied wattage and the thermistor self heating in terms of temperature rise. This relationship is defined as follows:

$$\delta = \frac{P}{\Delta T}$$

Where:

P = power dissipated in watts
ΔT = the rise in temperature (˚C)
The dissipation factor (δ) is expressed in units of mW/˚C.

A particular value of δ will correspond to the amount of power necessary to raise the body temperature of the thermistor by 1˚C. Because the dissipation factor, δ, is dependent upon a number of factors, the values listed in the data sheets are for reference only.

Time constant (τ)

The thermal time constant for a thermistor is defined as the time required for a thermistor to change 63.2% of the difference between the initial temperature of the thermistor and that of its surroundings when no power is being dissipated by the thermistor. The value of τ defines a response time for the thermistor when it has been subjected to a step change in temperature. For example, a thermistor that has been in an ambient temperature of 25˚C for a period of time long enough for it to reach equilibrium, is then moved to an environment where the temperature is 75˚C. The thermistor will not immediately indicate a resistance corresponding to the new temperature but rather will exponentially approach the new resistance value. For measurement purposes, the resistance value that corresponds to the temperature for τ will correspond to 63.2% of the temperature span, i.e.

$$T_{\tau} = 0.632 \, (75\text{-}25) = 31.6 + 25 = 56.6˚C$$

Therefore the temperature that the part must reach is 56.6˚C. The resistance of the part at that temperature can be calculated using the Steinhart-Hart equation or an approximation can be used. For example for SS&C part number A1004Z-C3, using the equation, the value at 56.6˚C should be 2814Ω. Therefore, to find the value for τ, we would monitor the resistance value of the part using a multimeter or similar instrument. The part should start at 25˚C where the resistance should be 10,000Ω. The time that the part takes to reach 2814Ω once the part is moved to the new temperature of 75˚C will correspond the value of τ and will have the units of seconds. The factors that affect τ are similar to those that affect δ and include the mass of the thermistor, mounting, environment and other factors.