How to select an NTC Thermistor

1. DISSIPATION CONSTANT (D.C.)

The dissipation constant is the amount of power (expressed in milliwatts) required to self-heat the thermistor suspended by its two-inch leads in still air 1 °C above its environment. The dissipation constant of NTC thermistor / NTC thermistor sensor assembly is typically defined as the ratio (at a specified ambient temperature) of the power dissipated in the thermistor to the resultant change in the temperature of the thermistor.

This constant (expressed as the power in milliwatts required to self-heat the thermistor 1 °C above ambient temperature) increases slightly with increasing temperature. The lead length and type of lead, the type of encapsulating material (epoxy, Durez, stainless steel probe, thermoplastic probe, etc.) the mounting of the NTC thermistor / assembly, the medium of the surrounding environment (flowing gas, still air, water, oil, etc.) and other factors generally determine the dissipation constant of an NTC thermistor / NTC thermistor sensor assembly.

Given the variables that affect D.C., it is recommended that a prototype should be tested under actual operating conditions to determine the maximum allowable input current. The current through the thermistor must be small enough to produce negligible self-heating error in the thermistor at the maximum measuring or controlling temperature. At the same time, the current should be as large as possible to maximize system sensitivity.

If the rate of heat loss under actual operating conditions could be fixed and was constant from system to system, the D.C. would only be a consideration for determining the maximum power dissipated and an offset allowance could be made. For example, if the D.C. of a thermistor assembly had been determined as 3 mW/°C in a stirred oil bath (the medium to be measured) and it was desired to measure the oil bath to an absolute temperature accuracy of ± 0.1 °C, the maximum power that should be developed in the thermistor by the measuring current is 0.15 mW.

This is to keep the self-heat factor to 50 % or less of the measurement accuracy.

The formula for this is:

3 mW/°C x 0.1 °C x 50 % = 0.15 mW

The D.C. of an NTC thermistor/NTC thermistor sensor assembly can be determined by first measuring the zero-power resistance of the NTC thermistor at two temperature points 10 °C to 25 °C apart. The thermistor is then placed in series with a variable voltage supply, a current meter, and a sufficiently large enough resistor to prevent too much current flowing through the circuit and allowing the thermistor to “run-away”. A high resistance voltmeter is connected across the thermistor. The power supply is then gradually increased until the voltage across the thermistor and the current through it indicate a resistance equal to the measured resistance at the upper temperature. This is determined by using Ohm’s law E ÷ I = R (E = volts, I = current, R = resistance). The D.C. is then calculated by dividing the power dissipated in the NTC thermistor by the temperature difference between the two measured temperatures. Power is calculated by using Ohm’s law, P = E x I.

2. THERMAL TIME CONSTANT (T.C.)

The time constant is the time in seconds required for the thermistor to change through 63.2 % of the difference between its initial and final body temperatures, when subjected to a step change in temperature under zero-power conditions. Since the NTC thermistor’s T.C. is determined by the same factors as D.C. (i.e., encapsulation, mounting, lead length, etc.), a prototype should be built if T.C. is important.

The time constant is determined by measuring the resistance of the thermistor at three temperature points, the middle point being 63.2 % of the difference between the upper one and the lower one. A precision bridge is set for the middle temperature resistance with the bridge voltage supply set so as not to produce the self-heat error. An auxiliary bridge voltage is set for the higher temperature resistance. The thermistor is placed in the operating medium at the lower temperature and is connected to the auxiliary bridge. The auxiliary bridge is adjusted to balance the bridge, which in effect, will self-heat the thermistor to the upper temperature. The thermistor is then immediately switched to the precision bridge.

The time required for the precision bridge to balance is the time constant of the NTC thermistor / NTC thermistor sensor assembly in the operating medium.

3. SELECTION OF RESISTANCE VALUE

Typically, NTC thermistors are specified and/or referenced to +25 °C. However, it is equally important to consider the minimum and maximum resistance values at the extremes of the operating temperature range.

The minimum resistance at the maximum temperature point must not be too low to meet the input requirements of the measuring circuit. If the resistance is too low, errors due to contact resistance, line resistance and self-heating increase.

It is recommended to have at least 500 W to 1000 W at the high end of the temperature range.

Conversely, the maximum resistance at the minimum temperature point must not be too high for the measurement circuit input. Range switching with two or more probes should be considered if the minimum / maximum resistance values cannot be met with one thermistor.

Sensitivity also is an important consideration in the selection of the correct resistance value. Usually, the minimum and maximum allowable resistance values typically limit this selection. It then must be determined which resistance values maximize the output of the measuring system over the entire range, taking into consideration the maximum input current as determined by the dissipation constant and allowable self-heat error.

4. R-T CURVE SELECTION

At present, 11 R-T curves are available from Vishay Dale. Each material has a different R-T characteristic. Given the different resistivity of the different R-T materials and the desirability of maintaining uniformity in size, not all resistance values (R_{25}) are available in all R-T curves.

Once the minimum resistance at the maximum temperature is determined, divide this resistance value by a given R-T/R_{25} ratio from one of any of the R-T curves to determine an approximate R_{25} value. (Note: R-T ratio tables in 1 °C increments are included on pages 11 to 16.) If the R_{25} value is not available in one R-T curve, select another until an appropriate R-T curve is determined. Then, select a standard R_{25} value that is closest to the approximate value. Calculate the maximum resistance at the minimum temperature by multiplying the selected R_{25} by the given R-T/R_{25} ratio. If the selected R-T curve and R_{25} value meet the predetermined minimum resistance, maximum resistance and sensitivity of the measurement system, then tolerance is the next consideration.

5. TOLERANCE

Most temperature measurement or control applications express their limitations or accuracy in temperature units (i.e. ± 1.0 °C). When designing a system, it is important to consider the overall measurement accuracy of all components. A ± 1.0 °C thermistor, coupled with a ± 1.0 °C system, will insure measurement accuracy to ± 2.0 °C.

Thermistors may be specified with either a temperature tolerance or a resistance tolerance at either a single temperature point or over a temperature range. If the required temperature measurement accuracy is over a temperature range, it is more practical to specify a temperature tolerance in lieu of a resistance tolerance. This is because a resistance tolerance specification over a range will not necessarily guarantee that the required system accuracy will be met unless the nonlinear NTC (negative temperature coefficient) is taken into consideration.

NTC is expressed in % resistance change per degree C. Since one NTC resistance change is approximately equivalent to a 1° temperature change, NTC is useful in specifying temperature tolerances. NTC's are given on the Vishay Dale Specification Sheet in 10 degree increments; however, the NTC may be calculated at any temperature point using a 1 °C R-T table.

Example: What is the NTC of 10 000 W (R_{25}) of a Curve 1 thermistor at +44 °C?

$$100\left(\frac{1}{4543\ \Omega \text{ at } 44\ °C} \times \frac{4368\ \Omega \text{ at } +45\ °C - 4725\ \Omega \text{ at } +43\ °C}{2}\right) = 3.9$$

$$\left(NTC = \frac{1}{R} \times \frac{dR}{dT}100\right)$$

To determine the resistance tolerance at any given temperature point, simply multiply the specified temperature tolerance by the NTC at the given temperature.

Example: What are the resistance tolerances at 0 °C, +25 °C and +0 °C for a Curve 1 thermistor with a ± 0.5 °C temperature tolerance over the range of 0 °C to +70 °C?

R0 = ± 0.5 °C x - 5.1 % = ± 2.55 % resistance tolerance

R25 = ± 0.5 °C x - 4.4 % = ± 2.2 % resistance tolerance

R70 = ± 0.5 °C x - 3.4 % = ± 1.7 % resistance tolerance

It may now be clear why a single resistance tolerance over a temperature range may not be practical for a particular temperature measurement application.

If a single temperature point is the only design specification, NTC and manufacturing tolerances are useful in determining temperature tolerances at other temperature points. Manufacturing tolerance is given on the Vishay Dale Specification Sheet in a ± % resistance tolerance. Point-matched specifications must have the difference in deviation between the specified temperature point and any other temperature point of interest added to the resistance tolerance at the specified temperature.

Example: What are the resistance tolerances at 0 °C and +50 °C for a standard 1M1002?

R0 = ± 10 % + ± 1.1 % = ± 11.1 % resistance tolerance

R25 = ± 10 % + ± 0.0 % = ± 10 % resistance tolerance

R50 = ± 10 % + ± 1.1 % = ± 11.1 % resistance tolerance

To determine the temperature tolerance at any temperature point, divide the resistance tolerance by the NTC at that point.

Example: What is the temperature tolerance at 0 °C for a 1M1002?

± 11.1 % ÷ -5.1 % = ± 2.2 °C temperature tolerances.

It should be noted that the manufacturing tolerances listed on the Vishay Dale Specification Sheet are all referenced at +25 °C. If the thermistor is referenced at a temperature other than +25 °C, then the total difference in deviation between the two points, if the +25 °C is between them, is the sum of the maximum deviations listed at each point.

Example: What is the maximum resistance tolerance of a Curve 1 thermistor at 0 °C if the specified tolerance is ± 5 % at +70 °C?

(± 5 % resistance tolerance at +70 °C) + (MT ± 1.8 % at +70 °C) + (MT ± 1.1 % at 0 °C) = ± 7.9 % resistance tolerance at 0 °C.

6. TOLERANCE AVAILABILITY VS R-T CURVE

Not all temperature / resistance tolerances are available in all R-T curves. If a temperature tolerance over an extended temperature range is required, then at present, Curves 1, 2, 4, 8, or 9 may be selected. All other curves may be specified to a resistance or temperature tolerance at a single temperature point. Curves 12 and 13 may only have ± 5 % or ± 10 % resistance tolerances specified. Contact the factory for further information.

7. TOLERANCE AVAILABILITY VS CONFIGURATION

Not all temperature/resistance tolerances are available in all configurations. Basically, hybrids, uncoated NTC thermistors without leads and uncoated NTC thermistors with leads are only available in ± 5 % or ± 10 % point matched resistance tolerances.

8. MEASUREMENT ACCURACY

Thermistor resistance measurements must be made at precisely controlled temperature while applying essentially zero-power to assure measurement accuracy.

RESISTANCE-TEMPERATURE RELATIONSHIP

Many empirical equations have been developed over the years in an attempt to accurately describe the non-linear resistance-temperature dependence of NTC thermistors.

An early equation called the “Beta” formula proved to be useful over narrow temperature ranges for broad tolerances. The Beta formula may be written using a single material dependent constant B as:

$$R(T) = R(To)\exp\left[B\left(\frac{1}{T} - \frac{1}{To}\right)\right]$$

where R (T) is the resistance at the temperature T in Kelvin and R (To) is a reference point at temperature To. The Beta formula requires a two-point calibration, but under the best of conditions is not accurate to ± 1 °C over the range of 0 °C to +100 °C and typically not to ± 5 °C over our published temperature ranges.

The best empirical expression published to date is the Steinhart-Hart equation written explicitly in temperature T as:

$$\frac{1}{T} = A + B(\ln R) + C(\ln R)^3$$

where In R is the natural logarithm of the resistance R at temperature T and the A, B, and C are derived coefficients from actual measurement. This form of the Steinhart-Hart equation requires a minimum of three calibration points to determine the derived coefficients. Typical accuracies would be less than ± 0.15 °C over the range of -50 °C to +150 °C.

If the temperature points selected from the R-T tables to calculate A, B, and C lie within a +100 °C range, the accuracy is better than ± 0.01 °C, assuming measurement accuracy to at least four significant figures and preferably five.

The Steinhart-Hart equation is an approximation. If a tighter tolerance than guaranteed is desired, then each thermistor must be individually calibrated.