Testing and Calibration of Thermistors

The very factors which make thermistors more useful than other temperature detectors, namely small size, fast response, and high sensitivity, also present problems in their testing and calibration.

In general, thermistors and assemblies should be calibrated in a well-circulated temperature-controlled liquid bath. The bath liquid should be chosen to provide low electrical conductivity, low viscosity and high thermal conductivity. The liquid volume of the bath should be at least 1000 times the volume of the test fixture and assemblies that are placed in the bath. The heat capacity of the bath should be high enough so that the bath temperature is not changed significantly by the immersion of the thermistor fixture and assembly.

Thermistors are specified in terms of nominal resistance values at one or more discrete temperatures with stated tolerances on both the resistance and temperature. To properly evaluate whether or not a thermistor meets its specifications, it is necessary that the testing facility either pull their limits in (for manufacturers) or open their limits (for users) by the total measurement uncertainty. The total uncertainty includes both the temperature measurement uncertainty and the resistance measurement uncertainty.

Temperature Measurement Uncertainties

The factors which affect the temperature measurement uncertainty are:

Temperature Control of the Testing Medium

This can vary between ±0.001°C for a sophisticated precision laboratory bath to as much as ±3°C for bench top testing.

Accuracy and Precision of the Temperature Monitor

The temperature monitor can consist of any of the following units. The accuracy and stability of each unit is an important consideration. The reference works cited contain more detailed information regarding each type of temperature monitor.

1) Standard platinum resistance thermometer (SPRT). These standards have an uncertainty of about 0.001°C within the temperature ranges over which most thermistors are operated. [Reference: J.L. Riddle, G.T. Furukawa, and H.H. Plumb, "Platinum Resistance Thermometry", National Bureau of Standards Monograph 126 (April 1972), Available from U.S. Government Printing Office, Washington, DC, Stock No. 0303-01052, B. W. Mangum, "Platinum Resistance Thermometer Calibrations", NBS Special Publication 250-22, 1987, B.W. Mangum and G.T. Furukawa, "Guidelines for Realizing the Internation Temperature Scale of 1990 (ITS-90)", NIST Technical Note 1265, 1990.]

2) Thermistor temperature standards. Thermistor standards are available from Thermometrics, Inc. with accuracies that vary between 0.001°C and 0.01°C. [Reference: Product Data Section of this Catalog; Type "S", "AS", "ES" and "CSP".]

3) Precision mercury-in-glass thermometers for 0°C and the range of 24°C to 38°C. The maximum uncertainty associated with these thermometers is 0.03°C. [Reference: Mangum, B.W., and J.A. Wise, Standard Reference Materials: Description and Use of Precision Thermometers for the Clinical Laboratory, SRM 933 and SRM 934, NBS Special Publication 260-48 (May 1974), Available from US Government Printing Office, Washington, DC, SD Catalog No. C13.10:260-48.]

4) Resistance Temperature Detectors (RTD's). Platinum RTD's for commercial and industrial use (not SPRT's) are available with accuracies of ±0.1°C or ±0.25°C. The stability and repeatability of some of the better RTD's on the market makes them suitable for calibration of individual units to within ±0.01°C. Such units should be checked for stability and hysteresis prior to calibration.

5) Liquid-in-glass thermometers. Accuracies attainable with liquid-in-glass thermometers for various graduation intervals have been published by ASTM. Although accuracies in the range of ±0.01°C to ±0.03°C are shown for totally immersed thermometers under some conditions, the practical realization of accuracies better than ±0.03°C is very difficult to achieve. Typically, the accuracy of liquid-in-glass thermometers ranges between ±0.1°C and ±0.5°C.

6) Thermocouples. A joint ANSI / ASTM specification lists the limits of error for thermocouples. The errors for various thermocouple types and temperature ranges are expressed in terms of a temperature accuracy or a percent of reading, whichever is greater. As a result, the best accuracies one can expect from a thermocouple (special limits of error) are on the order of ±0.5°C to ±1.1°C. Typically, the best accuracies obtained are on the order of 1.0°C to 2.2°C. [Reference: Standard Temperature-Electromotive Force (EMF) Tables for Thermocouples, ANSI/ASTM E220-77, ASTM Standards on Thermocouples, #06-5200077-40, p. 24, American Society for Testing and Materials (January 1978).]

7) Quartz thermometers. A quartz thermometer is also available which has a reported accuracy of ±0.04°C from -50°C to +150°C and ±0.075°C from -80°C to +250°C. [Reference: Quartz Thermometer, Model 2804A, Test and Measurement Catalog, p. 427, Hewlett Packard Company (1991).]

Electrical Properties

There are three basic electrical characteristics of thermistors which account for virtually all of the applications in which thermistors may be used. These are:

a) Current-Time Characteristic

b) Voltage-Current Characteristic

c) Resistance-Temperature Characteristic

There are also several applications where the thermistor is indirectly heated by some form of resistive element. These applications are merely special cases of one of the three basic electrical characteristics.

Current-Time Characteristic

In our analysis of the thermal properties of thermistors, we observed that a self-heated thermistor exhibits a body temperature rise that is a function of time. This is mathematically expressed in equation (6).

A transient condition exists in a thermistor circuit from the time at which power is first applied from a Thevenin source, ***(t=0)***, until the time at which an equilibrium condition is achieved, ***(t>>τ)***. Generally, the excitation is considered to be a step function in voltage through a Thevenin equivalent source. During this time the current will rise from an initial value to a final value and this current change as a function of time is called the “Current-Time Characteristic”.

The Current-Time Characteristic is not a simple exponential relationship. The rate of current change will be initially low due to the high resistance of the thermistor and the added source resistance. As the device begins to self-heat, the resistance will decrease rapidly and the rate of current change will increase. Finally, as the device approaches an equilibrium condition, the rate of current change will decrease as the current reaches its final value.

The factors which affect the Current-Time Characteristic are the heat capacity of the device ***C***, the dissipation constant of the device δ, the source voltage, the source resistance and the resistance of the device at a specified ambient temperature. The initial and final current values and the time required to reach the final current value can be altered as needed by proper circuit design.

The Current-Time Characteristic is used in time delay, surge suppression, filament protection, overload protection and sequential switching applications.

Voltage-Current Characteristic

Once a self-heated thermistor has reached a condition of equilibrium, the rate of heat loss from the device will be equal to the power supplied. This was discussed in our analysis of the thermal properties of thermistors. It is mathematically expressed by equation (8) which can be rewritten as:

$$P = \delta\left(T - T_A\right) = E_T I_T$$

In our discussion of the dissipation constant, δ, we observed that it was influenced by the thermal conductivity and relative motion of the medium, heat conduction through the leads, free convection and radiation. If the dissipation constant variations are negligible for a specified medium and set of conditions, and the resistance-temperature characteristic is known, then equation (8) can be solved for the static voltage-current characteristic. Usually this characteristic is plotted on log-log coordinates in thermistor literature, where lines of constant resistance have a slope of +1 and lines of constant power have a slope of -1. Figure 5 shows the static voltage-current characteristic for a typical thermistor plotted on log-log coordinates.

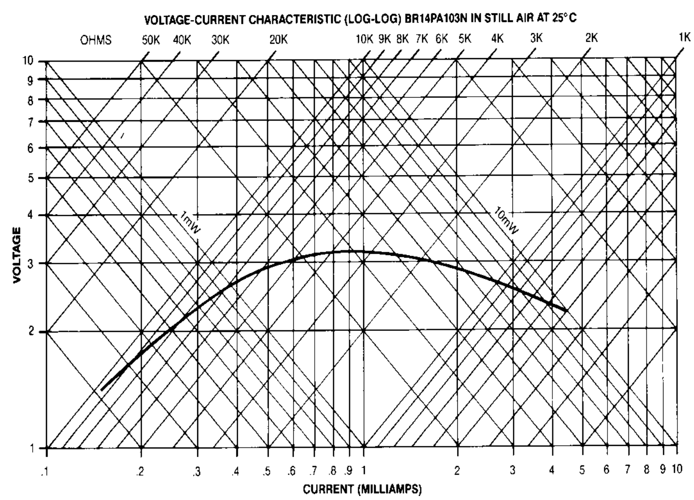

Figure 5

For some applications it is more convenient to plot the static voltage-current characteristic on linear coordinates as shown in Figure 6.

At very low currents the amount of power dissipated in the thermistor is negligible. The voltage-current characteristic will be tangential to a line of constant resistance that is equal to the zero-power resistance of the device at the specified ambient temperature. In this portion of the curve, an increase in current produces an increase in the voltage drop across the thermistor according to Ohm’s law.

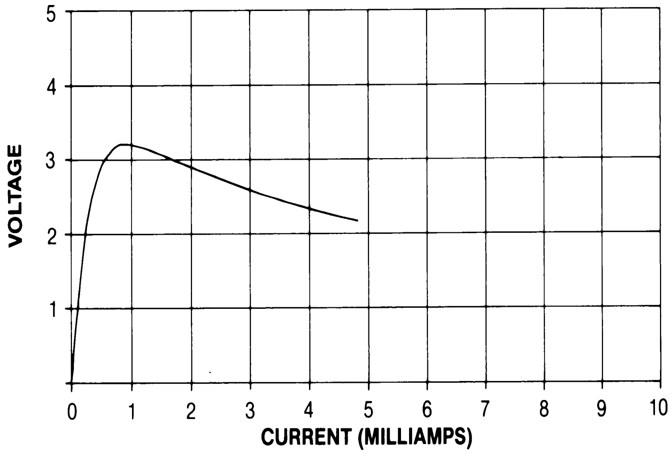

Figure 6

As the current continues to be increased, the effects of self-heating become more evident and the temperature of the thermistor rises with a resultant decrease in its resistance. For each subsequent incremental increase in current there is a corresponding decrease in resistance. Hence, the slope of the voltage-current characteristic DE/DI, decreases with increasing current. This continues until a current value I_P, is reached for which the slope becomes zero and the voltage reaches a maximum value E_P. As the current is increased above the value of I_P, the slope of the characteristic continues to decrease and the thermistor exhibits a negative resistance characteristic.

At very large values of current, where the resistance of the thermistor becomes quite small, the effects of leadwires and contact resistance will start to be observed. The slope of the voltage-current characteristic will begin to increase slightly until it goes through zero again and the voltage reaches a minimum value. Afterward, the voltage-current characteristic increases as the voltage drop across the thermistor becomes due primarily to the resistance of the leadwire and contacts. Normally, a self-heated thermistor would never be operated in a condition such that the voltage drop across the thermistor was significantly affected by the leadwire or contact resistance. Such operation would usually require a resultant body temperature of the thermistor that is considerably beyond the maximum temperature for best stability and performance.

A maximum power rating as well as a power derating curve is given for each thermistor style in the product data section. This data is normally given for the operation of the thermistor in a still air environment. The ratings are such that the thermistor is operated in a safe mode. Care should be exercised when designing a circuit for a self-heated application so that the thermistor is operated within the maximum power limitations.

There are many applications which are based upon the static voltage-current characteristic. These applications can be grouped according to the type of excitation which is employed to vary the voltage-current characteristic.

The first major group involves applications where the dissipation constant is varied. This can be accomplished by changing the thermal conductivity of the medium, the relative motion of the medium or the heat transfer from the thermistor to its surroundings. Typical applications would include vacuum manometers, anemometers, flow meters, liquid level, fluid velocity, thermal conductivity cells, gas chromatography and gas analysis.

The second major group involves applications where the electrical parameters of the circuit are varied. This would involve a change in the Thevenin source voltage or source resistance. Typical applications would include automatic gain or amplitude control, voltage regulation, equalization, volume limiters, signal compression or expansion and switching devices.

The third and fourth major groups involve applications where the ambient temperature is varied. In one case the change is thermal, while in the other case the change is due to radiation absorbed by the thermistor. Temperature control and alarm indication are examples of applications where the change is thermal. Microwave power measurement is an example of an application where the change is due to absorbed radiation.

Resistance-Temperature Characteristic

The definition of a thermistor, according to MIL-T-23648, states that the device, "is a thermally sensitive resistor whose primary function is to exhibit a change in electrical resistance with a change in body temperature."

There are many applications based upon the resistance-temperature characteristic and they can be grouped into the general categories of resistance thermometry, temperature control or temperature compensation. In the previous discussions of the current-time and voltage-current characteristics, we examined devices that were operated in a self-heated mode. As such, those devices were heated above the ambient temperature by the power being dissipated in the thermistor. For most applications in resistance thermometry or temperature control, the self-heating effect is undesirable. The zero-power resistance-temperature characteristic must be determined for thermistors that are used in measurement, control or compensation applications.

The zero-power resistance of a thermistor, R_T, at a specified temperature, T, is the DC resistance measured when the power dissipation is negligible. By definition in MIL-T-23648, the power is considered to be negligible when "any further decrease in power will result in not more than 0.1 percent (or 1/10 of the specified measurement tolerance, whichever is smaller) change in resistance."

The exact electrical conduction mechanism for metal oxide thermistors is still not completely understood. At present, there are two models which are used to provide an explanation for the resistance-temperature behavior of metal oxide thermistors.

One model for electrical conduction theory involves the so-called "hopping" mechanism which is observed in ferrites and manganites that have a spinel crystal structure. In this model, conduction occurs when charge carriers "hop" from one ionic site in the spinel lattice to an adjacent site.

The other model is based upon a consideration of "energy bands" which are the basis of semiconductor theory. In this model, conduction is explained in terms of "intrinsic" and "extrinsic" charge carriers that are excited across an energy "gap". According to the this model, the charge carriers are the result of physical impurities rather than chemical impurities, and occur from either an excess or a deficiency of oxygen atoms in the crystal lattice.

Both of the conduction models have difficulties when it comes to a complete explanation of resistance-temperature characteristics of metal oxide thermistors. The slope of the ***ln*** $\boldsymbol{R_T}$ versus ***1/T*** curve departs slightly from linearity, especially at lower absolute temperatures. This fact is better explained by the action of the "extrinsic" charge carriers in the semiconductor model, however, metal oxide thermistors are not simple monocrystalline devices. They are polycrystalline, granular structures, and can be composed of several metal oxides with multiple valences. Physical defects, boundary conditions and/or oxygen concentrations within the structure can influence the electrical conduction mechanism.

There are a number of equations which can be used that will adequately define the resistance-temperature characteristic of the devices.

The resistance-temperature characteristic of semiconductors is very often plotted with the logarithm of specific resistance expressed as a function of the reciprocal of absolute temperature. In Figure 7, the resistance-temperature characteristics of three commonly used thermistor materials are shown in terms of their specific resistances and inverse absolute temperatures. The resistance ratio-temperature characteristics for these materials are specified in MIL-T-23648.

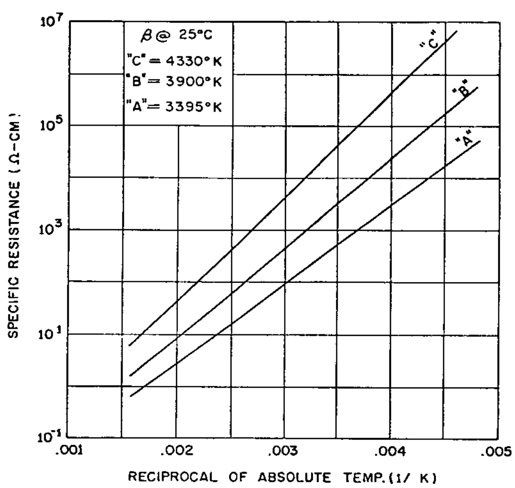

Figure 7

It can be demonstrated that, over any specified temperature range for which the slope of a given material curve may be considered to be constant, a straight line relationship exists between ***ln*** $\boldsymbol{R_T}$ and ***1/T*** that can be expressed mathematically as follows:

$$\ln R_T = A + \frac{\beta}{T} \qquad \textbf{(11)}$$

where: $\boldsymbol{T}$ is absolute temperature in Kelvins (°C + 273.15) and the slope of the curve, ***ß***, is referred to as the "beta" or "material constant" of the thermistor.

If we let $\boldsymbol{R_T = R_{T0}}$ at a reference temperature $\boldsymbol{T = T_0}$, then equation (11) may be written as

$$\ln R_{T0} = A + \frac{\beta}{T_0} \qquad \textbf{(12)}$$

Subtracting equation (12) from equation (11) and solving for $\boldsymbol{R_T}$ yields

$$R_T = R_{T0} \exp \frac{\beta(T_0 - T)}{T T_0} \qquad \textbf{(13)}$$

If temperature is the parameter to be determined from resistance measurements, then equation (13) can be rewritten as

$$t(^\circ C) = \left[\frac{1}{\beta} \ln\left(\frac{R_T}{R_{T0}} \right) + \frac{1}{T_0} \right]^{-1} - 273.15 \qquad \textbf{(14)}$$

Because equations (13) and (14) have two unknown constants, there are two calibration points required to evaluate these constants for any specific thermistor. If $\boldsymbol{R_{T0}, T_0}$ represents one of the calibration points, and $\boldsymbol{R_T = R_{T1}}$ at $\boldsymbol{T = T_1}$ represents the other, then the material constant, ***ß***, can be found, from equation (13) to be

$$\beta = \frac{T_1 T_0}{T_0 - T_1} \ln\left(\frac{R_{T1}}{R_{T0}} \right) \qquad \textbf{(15)}$$

By definition, the temperature coefficient of resistance is given by

$$\alpha = \left(\frac{1}{R_T} \right) \frac{dR_T}{dT} \qquad \textbf{(16)}$$

Solving equation (13) for $\boldsymbol{\alpha}$ yields

$$a = -\frac{b}{T^2} \quad (17)$$

As we have previously noted, the ***ln R$_T$*** vs ***1/T*** characteristic exhibits some non-linearity. The value for the slope, Beta, decreases with decreasing temperature. Consequently, the equations cited above are valid only for small temperature spans for which the ***ln R$_T$*** vs ***1/T*** characteristic approximates a straight line. At temperatures above 0°C, the uncertainties associated with the use of equations (13) and (14) are as follows:

Temperature span (°C)	10	20	30	40	50
Temperature uncertainty (°C)	0.01	0.04	0.10	0.20	0.30

For temperatures in the range of -80°C to 0°C, where the ***ln R$_T$*** vs ***1/T*** characteristics becomes more non-linear, the temperature spans should be reduced by a factor of 2 to 3 in order to maintain the same uncertainty. The use of equations (13) and (14) at temperatures below -80°C has not been fully investigated and their use can not be recommended except for very narrow temperature spans.

Early investigations of thermistors attempted to provide improved fit of resistance-temperature data by taking into account the slight dependence of beta on temperature. Some of the resulting empirical equations are as follows:

$$R_T = AT^{-C} \exp\left\{\frac{D}{T}\right\} \quad (18a)$$

$$\ln R_T = a + \frac{b}{T+q} \quad (18b)$$

$$\ln R_T = a + \frac{b}{T+q} + cT \quad (18c)$$

While these equations offer a more accurate representation of the resistance-temperature characteristic, their solutions are more difficult and they are not widely used in thermistor applications.

The more recent literature on thermistors accounts for the non-linearity of the ***ln R$_T$*** vs ***1/T*** characteristic by using the standard curve fitting technique of considering ***ln R$_T$*** to be a polynomial in ***1/T*** or vice versa. These equations provide a very accurate representation of the non-linear resistance-temperature characteristics typical of commercial thermistors. The equations are valid over wide temperature ranges. The order of the polynomial required depends upon the temperature range and the non-linearity of the thermistor material system.

$$\ln R_T = A_0 + \frac{A_2}{T^2} + \ldots + \frac{A_N}{T^N} \quad (19)$$

$$\frac{1}{T} = a_0 + a_1(\ln R_T) + a_2(\ln R_T)^2 + \ldots + a_N(\ln R_T)^N \quad (20)$$

Excellent results have been obtained with the use of a third order polynomial. Hence, the resistance-temperature characteristic may be expressed as:

$$\frac{1}{T} = a_0 + a_1[\ln R_T] + a_2[\ln R_T]^2 + a_3[\ln R_T]^3 \quad (21)$$

$$\ln R_T = A_0 + \frac{A_1}{T} + \frac{A_2}{T^2} + \frac{A_3}{T^3} \quad (22)$$

The use of equation (21) was originally proposed by Steinhart and Hart for the oceanographic range of -2°C to +30°C. They also indicated that there was no significant loss in accuracy when the squared term, **[*a_2{ln R_T}^{2}*]**, was eliminated. Consequently, they proposed the use of:

$$\frac{1}{T} = b_0 + b_1[\ln R_T] + b_3[\ln R_T]^3 \quad (23)$$

The work of Steinhart and Hart was confirmed by studies conducted by B.W. Mangum at NIST and R. Koehler at Woods Hole Oceanographic Institute. However, they found that greater accuracy is obtained when the squared term of equation (21) is retained. Mangum found this to be particularly true at low temperatures (-140°C to -120°C) where the deviation from linearity in the slope of the ***ln R$_T$*** vs ***1/T*** characteristic is more pronounced. For the oceanographic range of -2°C to 30°C, the interpolation errors resulting from the use of equations (21) and (23) were found to be approximately 0.001°C. Mangum has also reported that equation (23) is valid when used over the range of 0°C to 70°C based on calibration at fixed points between 0.01°C and 58.0805°C. By calibrating thermistor thermometers at the fixed points provided by water, gallium and succinonitrile for the determination of the equation constants, he found that equation (23) provided values which agreed with calibrations performed with an SPRT to within ±0.001°C.

Thermometrics, Inc. has reported on a comprehensive evaluation of equation (22) for describing the resistance-temperature characteristics of thermistors. Seventeen different thermistor materials representative of those used in the manufacture of bead style thermistors were evaluated over the range of -80°C to +260°C (193.15K to 533.15K). The material systems investigated encompassed a span of resistivities (2Ω-cm to 300 kΩ-cm) and a range of resistances at 25°C (10Ω to 2 MΩ) which are normally available for commercial thermistors. The temperature range represents the normal span where thermistors would be most likely applied for temperature measurement or control. A description of the thermistors tested, the test apparatus, the measurement uncertainties, the evaluation of test results and the conclusions obtained are completely detailed in Thermometrics, Inc. Application Note #216.

Thermometrics, Inc. also has investigated the loss in accuracy introduced by eliminating the squared term in equation (22). For this condition, equation (22) reduces to:

$$\ln R_T = B_0 + \frac{B_1}{T} + \frac{B_3}{T^3} \qquad (24)$$

The interpolation error introduced by equation (24) depends upon the degree of non-linearity exhibited by the ***ln R_T*** vs ***1/T*** characteristic. This, in turn, depends upon the material system used, the temperature range (non-linearity increases at low temperatures), and the temperature span considered.

The results of the investigations conducted at Thermometrics, Inc. indicate excellent curve fit using third degree polynomials and are summarized in Table III.

Summary of Curve Fitting Errors

A) Full third degree polynomials, Equations (21) and (22), do not introduce interpolation errors which exceed the total measurement uncertainties (typically .005°C to .010°C) for:

- a1) 100°C spans within the range of -80°C to +260°C.
- a2) 150°C spans within the range of -60°C to +260°C.
- a3) 150°C to 200°C spans within the range of 0°C to +260°C, except that interpolation error begins to approximate the measurement uncertainties.

B) Third degree polynomials with the squared term eliminated, Equations (23) and (24), introduce interpolation errors which do not exceed the following conditions:

- b1) .001°C to .003°C error for 50°C spans and temperature range 0°C ≤ T ≤ 260°C.
- b2) .010°C to .020°C error for 50°C spans and temperature range -80°C ≤ T ≤ 0°C.
- b3) .010°C error for 100°C spans and temperature range 0°C ≤ T ≤ 260°C.
- b4) .020°C to .030°C error for 100°C spans and temperature range -80°C ≤ T ≤ 25°C.
- b5) .015°C error for 150°C span (50°C ≤ T ≤ 200°C)
- b6) .045°C error for 150°C span (0°C ≤ T ≤ 150°C)
- b7) .100°C error for 150°C span (-60°C ≤ T ≤ 90°C)
- b8) .080°C error for 200°C span (0°C ≤ T ≤ 200°C)

Table III

Equations (21) and (22) may be restated as:

$$t(°C) = \{a_0 + a_1[\ln R_T] + a_2[\ln R_T]^2 \ldots + a_3[\ln R_T]^3\}^{-1} - 273.15 \qquad (25)$$

$$R_T = exp\left(A_0 + \frac{A_1}{T} + \frac{A_2}{T} + \frac{A_3}{T}\right) \qquad (26)$$

where: ***T*** is absolute temperature in kelvins = °C +273.15

Because equations (25) and (26) each have four unknown constants, there are four calibration points required to determine these constants. These constants may be obtained from the solution of four simultaneous equations. The constants for equations (25) and (26) may also be obtained from a polynomial regression analysis when more than four points are given. Such an analysis statistically improves the accuracy of the data.

If we define the material constant, ***ß***, as the slope of the ***ln R_T*** vs ***1/T*** characteristic, then:

$$\beta = A_1 + \frac{2A_2}{T} + \frac{3A_3}{T^2} \qquad (27)$$

The temperature coefficient of resistance, α, defined by equation (16) may be obtained from equation (22) as:

$$\alpha = \left(\frac{1}{R_T}\right)\frac{dR_T}{dT} = -\left[\frac{A_1}{T^2} + \frac{2A_2}{T^3} + \frac{3A_3}{T^4}\right] \qquad (28)$$

It is of interest to note that the expression, $\alpha = -\beta/T^2$, from equation (17), is still valid as long as ***ß*** is considered to be a function of temperature, ***T***.

Equations (24) and (23) may be rewritten as

$$R_T = exp\left[B_0 + \frac{B_1}{T} + \frac{B_3}{T^3}\right] \qquad (29)$$

$$t(°C) = \left\{b_0 + b_1[ln\,R_T] + b_3[ln\,R_T]^3\right\}^{-1} - 273.15 \qquad (30)$$

Equations (29) and (30) both make use of three constants. Consequently, they require three calibration points and the solution of three simultaneous equations to determine the values of the unknown constants. When using these equations, the material constant, ***ß***, and the temperature coefficient of resistance, α, may be expressed as follows:

$$\beta = B_1 + \frac{3B_3}{T^2} \qquad (31)$$

$$\alpha = -\left(\frac{\beta}{T^2}\right) = -\left[\frac{B_1}{T^2} + \frac{3B_3}{T^4}\right] \qquad (32)$$

Although characteristic curves of ***ln R**$_T$* vs ***1/T*** are useful for deriving interpolation equations, it is more common for manufacturers to provide nominal thermistor resistance values at a standard reference temperature (usually specified as 25°C) as well as resistance-ratio vs temperature characteristics.

Resistance-Temperature Curves

In the Product Data Section the nominal resistance values at 25°C are given for each thermistor type on the specific product data sheet. Reference is also made to the applicable ratio-temperature table/curve for each nominal resistance value listed. The ratio-temperature tables and curves for NTC thermistors are given in Product Data Section.

Temperature Gradients Within the Medium

Of particular importance are temperature gradients between the thermistor under test and the temperature monitor (sensor). Such gradients can be minimized by using a well-stirred liquid bath. The thermal conductivity, and dielectric constant of the liquid should be high and its viscosity should be low.

Immersion Errors or Stem Effects for the Temperature Monitor

Generally, there is a heat-transfer path between the actual sensing element and the surrounding ambient environment which normally is at a different temperature than the calibration temperature. This can result in a monitor temperature that differs from the calibration medium by some factor. Unless the monitor has been calibrated for partial immersion, total immersion is recommended.

Self-heating Effects

For sensors, such as RTD's and thermistors, which require some power to be dissipated in the sensor during measurement, self-heating effects in the monitor must be considered.

Equipment Uncertainties

The uncertainties associated with any auxiliary equipment required for reading the monitor adds to the temperature uncertainty. For example, platinum SPRT's and RTD's have a temperature coefficient of resistance of about 0.4%/°C. To realize a temperature uncertainty of 0.001°C with an SPRT, a precision 4-wire bridge is required which is capable of accurately resolving better than 1 PPM (preferably 1 part in 10^7). For such measurements, a ratio bridge is frequently used which compares the reading to a 4-terminal standard resistor. To realize a 0.01°C measurement with a platinum RTD, the resistance measuring equipment must have an accuracy which is better than 0.004% and preferably 0.001%. With a thermistor standard, a 0.01°C measurement requires an instrument having an accuracy of better than 0.04% and preferably at least 0.01%.

Thermal Response of Monitor

The difference between the response time of the monitor and the thermistor under test is a major consideration. This is particularly true when an attempt is made to calibrate a fast response thermistor such as a small bead. The thermal mass of the monitor has the property of integrating the temperature fluctuations of the test medium. It is possible for the monitor to indicate that there is only a slight fluctuation in the temperature of the medium while, in fact, the thermistor under test could be experiencing very large temperature fluctuations. To minimize this problem, the thermistor can be mass-loaded, or, a heat sink can be affixed to both the monitor and the unit under test. A thermal integrating block is often used for this purpose.

Heat Capacity of the Medium

The heat capacity of the test medium must be sufficiently large compared with that of the thermistor or thermistor assembly and its associated fixture so that the temperature of the test medium is not changed when they are immersed. When this is not the case, enough time must be permitted to elapse for the total system to reach an equilibrium condition, after immersion.

Resistance Measurement Uncertainties

The factors which affect the resistance measurement uncertainty are:

Resistance Measuring Equipment

The accuracy, precision, stability, and temperature coefficient of the resistance measuring equipment must be considered.

Self-heating Error

The ratio of the power dissipated in the thermistor (by the test equipment) to the dissipation constant of the thermistor in the test medium determines the self-heat error.

Stability of the Thermistor Under Test

If a thermistor which has not had sufficient stability conditioning is calibrated at a low temperature and is subsequently calibrated at an elevated temperature, the high temperature exposure may create a shift in resistance which gives the appearance of a hysteresis effect. This may also occur if the thermistor is calibrated at a temperature above its maximum rated temperature.

Thermistor and Circuit Lead Resistance

In general, when the desired accuracy of the measurement requires a resistance resolution that is less than 1 Ohm, or when the absolute resistance of the thermistor at a specified temperature will be less than 1000 Ohms, the user must consider the following:

1. The contact resistance between the instrument and its measuring leads.
2. The contact resistance between the instrument leads and the fixture used to hold the thermistor. Table V
3. The temperature coefficient of the instrument and measuring leads.
4. The resistance of the thermistor leads and the ability to make contact on the thermistor leads at

exactly the same point each time a measurement is made. This is important when attempting to make measurements on thermistors with fine gauge platinum alloy leadwires such as small beads.

Thermal EMF Effects

Thermal EMF's can result at the instrument terminals, the connections between the instrument leads and the thermistor fixture, the connection between the fixture and the thermistor leads, and electrical connections between dissimilar metals within the fixture itself.

QUALITY ASSURANCE

Thermometrics maintains a system which complies with MIL-Q-9858. All of our bead and chip thermistors are designed to comply with MIL-T-23648. Every Thermometrics thermistor receives 100% electrical inspection as well as 100% visual and mechanical inspection. This is verified by additional QA sampling which varies with the application requirements (typically 0.65 AQL or 1.0 AQL). Our Applications Engineering Department will gladly provide assistance in selecting the best qualification and acceptance testing programs for any specific application. We can provide a low cost screening test or sophisticated qualification testing depending upon your requirements.