NTC Thermistor Thermal Features

AN-THM-004

This document tells how to consider Thermal Dissipation Constant when we use an NTC thermistor to measure the temperature, and how to design a circuit to achieve an expected accuracy based on a given Thermal Dissipation Constant.

As we all know that over any specified temperature range, the resistance versus temperature can be ideally described by the following formula:

$$R_T = R_{T0} \times e^{\frac{\beta(T0-T)}{T\times T0}} \quad (1)$$

Where:

- R_T is the NTC's resistance at an absolute temperature T expressed in Kelvins ($T = t℃ + 273.15$);
- R_{T0} is the NTC's resistance at an absolute temperature T0 (for instance, T_{25}), also expressed in Kelvins ($T0 = t0℃ + 273.15$);
- β is the NTC's material constant (K), represents the slow of thermistor R-T characteristic over the specified temperature range.
- T is the environment temperature that to be measured.

But, is the T really the data to show the actual temperature of the object be measured? In fact, in equation (1), T just indicates the body temperature of NTC thermistor itself. The accuracy depends on how small the difference between the object temperature and Thermistor's body temperature.

For sensors, such as RTDs and thermistors, which require some power do be dissipated in the sensor during measurement, self-heating effects in the monitor must be considered [1].

When an NTC thermistor is connected in a circuit, power is dissipated as heat and the body temperature of the thermistor will rise above the ambient temperature. The rate at which energy is supplied must be equal to the rate at which energy is lost plus the rate at which energy is absorbed (the energy storage capacity). [1]

$$\frac{dH}{dt} = \frac{dH_{Lost}}{dt} + \frac{dH_{Absorbed}}{dt} \quad (2)$$

The rate at which thermal energy is supplied to the thermistor in an electrical circuit is equal to the power dissipated by the thermistor [1].

$$\frac{dH}{dt} = P = I^2 \times R_T = E \times I \quad (3)$$

The rate at which thermal energy is lost from the thermistor to its surroundings is proportional to the temperature rise of the thermistor [1].

$$\frac{dH_{Lost}}{dt} = \delta \times \Delta T = \delta \times (T - T_A) \quad (4)$$

Where:

δ is the thermal dissipation constant, is defined as the ratio, at a specified ambient temperature, of a change in the power dissipation of a thermistor to the resultant body temperature change. The dissipation constant depends upon the thermal conductivity and relative motion of the medium in which the thermistor is located, as well as the heat transfer from the thermistor to its surroundings by conduction through the leads, by free convection in the medium and the by radiation. The thermal dissipation constant is not a true constant since it varies slightly with temperature, also with temperature rise. It is typically measured under equilibrium conditions [1].

While the rate at which thermal energy is lost from the thermistor to its surroundings is proportional to the temperature rise of the thermistor.

The rate at which thermal energy is absorbed by the thermistor to produce a specific amount of rise in temperature can be expressed as follows: [1]

$$\frac{dH_{Absorbed}}{dt} = S \times m\frac{dT}{dt} = C \times \frac{dT}{dt} \qquad (5)$$

Where:

S is the specific heat and m is the mass of the thermistor.
The product of the specific heat and the mass is the heat capacity (C) of the thermistor and is dependent upon thermistor materials and construction. Thus, the heat transfer equation for an NTC thermistor at any instant in time after power has been applied the circuit can be expressed as: [1]

$$\frac{dH}{dt} = P = I^2 \times R = E \times I = \delta(T - T_A)C\frac{dT}{dt} \qquad (6)$$

The solution of equation where the Power (P) is constant is:

$$\Delta T = (T - T_A) = \frac{P}{\delta}[1 - e^{-\frac{\delta}{C}t}] \qquad (7)$$

In the steady state condition, which means $\frac{dT}{dt} = 0$, or when t >> C/δ in equation above, a condition of equilibrium condition is achieved. The rate of heat loss is equal to the power supplied to the thermistor.

$$\delta(T - T_A) = \delta \times \Delta T = P = E_T I_T \qquad (8)$$

$$\Delta T = \frac{E_T I_T}{\delta} \qquad (9)$$

Where:
E_T is the steady state or static thermistor voltage;
I_T is the steady state or static thermistor current.

When the ambient temperature is T_A, but the resistance of the thermistor we get from the circuit is actually from a heated thermistor, and the body of the thermistor is $(T_A + \Delta T)$.

So if the driving current through the thermistor is big enough, thus the Power P (EI) is no negligible, The tolerance or error ΔT will be introduced into the result. [1]

When the power of driving a thermistor is reduced to an amount where the self-heating is considered negligible, then the heat transfer equation (6) can be re-written as follows [1]:

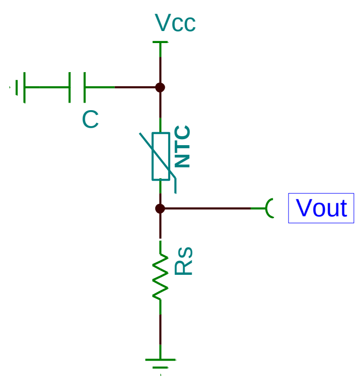
$$\frac{dT}{dt} \cong \frac{-\delta}{C}(T - T_A) \qquad (10)$$

Equation (10) is actually a mathematical statement of Newton's Law of cooling and has the following solution:

$$T \cong T_A + (T_{init} - T_A)e^{\frac{-\delta \times t}{C}} \quad (11)$$

When t >> $\frac{C}{\delta}$, T = T_A.

Where: T_{init} is the initial body temperature of thermistor.



Tips for selecting serial resistor Rs.

(1) Do not choose a resistor with too low resistance which will produce too much self-heating especially when the target temperature is relatively higher thus the thermistor's resistance will also decrease, and eventually the driving current through the thermistor increases significantly.

(2) If the driving current at the highest temperature will not produce too much current, then driving current will not exceed this value because that's the lowest resistance of the circuit, while the total resistance of thermistor's resistance plus the serial resistor's won't be less than it at any other temperature points.

(3) Use the thermal dissipation constant δ ($^{mW}/_{°C}$ or $^{mW}/_{K}$) to estimate the temperature tolerance introduced by the self-heating.

$$\Delta T \approx I^2 \times R_T / \delta$$

Where:

- I's unit is mA;
- R_T's unit is ohm;

Please be noted that the thermal dissipation constant is changing when the ambient temperature or thermal medium is changing.

(4) We may keep the driving current as low as possible provided that the sensitivity of the measurement circuit is still good enough. So that'll be a balance to be made during your application.

References
[1] Temperature Sensing Solutions, Thermometrics

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