

NTC Inrush Current Limiters

General technical information

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General technical information

1 Definition

As defined by IEC 60539, NTC (Negative Temperature Coefficient) thermistors are thermally sensitive semiconductor resistors which show a decrease in resistance as temperature increases. With $-2\%/K$ to $-6\%/K$, the negative temperature coefficients of resistance are about ten times greater than those of metals and about five times greater than those of silicon temperature sensors.

Changes in the resistance of the NTC thermistor can be brought about either externally by a change in ambient temperature or internally by self-heating resulting from a current flowing through the device. All practical applications are based on this behavior.

NTC thermistors are made of polycrystalline mixed oxide ceramics. The conduction mechanisms in this material are quite complex, i.e. either extrinsic or intrinsic conduction may occur. In many cases NTC thermistors have a spinel structure and then show valence conduction effects.

2 Manufacture

TDK thermistors are produced from carefully selected and tested raw materials. The starting materials are different oxides of metals such as manganese, iron, cobalt, nickel, copper and zinc, to which chemically stabilizing oxides may be added to achieve better reproducibility and stability of the thermistor characteristics.

The oxides are milled to a powdery mass, mixed with a plastic binder and then compressed into the desired shape. The thermistor material is compressed under very high pressure on pelleting machines to produce round, flat pieces.

The blanks are then sintered at high temperatures (between $1000\text{ }^{\circ}\text{C}$ and $1400\text{ }^{\circ}\text{C}$) to produce the polycrystalline thermistor body. Disks are contacted by baking a silver paste onto the flat surfaces, fitted with leads and then completely coated. Finally the thermistors are subjected to a special ageing process to ensure high stability of the electrical values. Otherwise the NTC resistance would possibly change even at room temperature due to solid-state reactions in the polycrystalline material.

Flow charts in the quality section of this book (see chapter "Quality and Environment") show the individual processing steps in detail. The charts also illustrate the extensive quality assurance measures taken during manufacture to guarantee the constantly high quality level of our thermistors.

3 Characteristics

A current flowing through a thermistor may cause sufficient heating to raise the thermistor's temperature above the ambient. As the effects of self-heating are not always negligible (or may even be intended), a distinction has to be made between the characteristics of an electrically loaded thermistor and those of an unloaded thermistor. The properties of an unloaded thermistor are also termed "zero-power characteristics".

3.1 Unloaded NTC thermistors

3.1.1 Temperature dependence of resistance

The dependence of the resistance on temperature can be approximated by the following equation:

$$R_T = R_R \cdot e^{B \cdot \left(\frac{1}{T} - \frac{1}{T_R} \right)} \quad (\text{formula 1})$$

R_T NTC resistance in Ω at temperature T in K

R_R NTC resistance in Ω at rated temperature T_R in K

T, T_R Temperature in K

B B value, material-specific constant of the NTC thermistor

e Euler number ($e = 2.71828$)

The actual characteristic of an NTC thermistor can be roughly described by the exponential relation. This approach, however, is only suitable for describing a restricted range around the rated temperature or resistance with sufficient accuracy.

3.1.2 Behavior in different media

As shown by equations (formula 9a) and (formula 9b) the voltage/current curve is influenced not only by the NTC resistance $R(T)$ but also by the dissipation factor δ_{th} . The dissipation factor, in turn, depends on size, shape and leads of the device as well as on the medium surrounding the thermistor.

The voltage/current curves specified in the data sheets apply to still air. In stirred air the dissipation factor increases and the V/I curve shifts towards higher values of voltage and current. The opposite applies when the thermistor is suspended in a vacuum.

The voltage/current curve thus indicates by which medium the thermistor is surrounded.

3.1.3 Maximum power rating P

P is the maximum power an NTC thermistor is capable of handling at a particular ambient temperature with its own temperature not exceeding the maximum category temperature. In addition to the ambient temperature, mainly the dissipation factor δ_{th} determines the power handling capability.

With known dissipation factor δ_{th} the maximum power handling capability can be calculated by:

$$P_{\max} = \delta_{th}(T_{\max} - T_A) \quad (\text{formula 2})$$

3.1.4 Dissipation factor δ_{th}

The dissipation factor δ_{th} is defined as the ratio of the change in power dissipation and the resultant change in the thermistor's body temperature. It is expressed in mW/K and serves as a measure for the load which causes a thermistor in steady state to raise its body temperature by 1 K. The higher the dissipation factor, the more heat is dissipated by the thermistor to the environment.

$$\delta_{th} = \frac{dP}{dT} \quad (\text{formula 3})$$

For measuring δ_{th} the thermistor is loaded such that the ratio V/I corresponds to the resistance value measured at $T_2 = 85^\circ\text{C}$.

$$\delta_{th} = \frac{V \cdot I}{T - T_A} = \frac{P}{T - T_A} \quad (\text{formula 4})$$

T Body temperature of NTC thermistor (85°C)

T_A Ambient temperature

Designing an NTC thermistor into a circuit will always produce some kind of increase in its body temperature that leads to falsification of the measured result in a temperature sensor application. To keep this small, make sure the applied power is as low as possible. No general details can be given for optimal wiring in a specific application because our products have a wide bandwidth of both resistance and thermal conductivity. Please note that all figures for the thermal characteristics of our NTC thermistors refer to still air. As soon as other ambient conditions apply (e.g. stirred air) or once a component obtained from TDK Electronics is subsequently prepared, the thermal characteristics illustrated in our data sheets are no longer valid.

3.1.5 Heat capacity C_{th}

The heat capacity C_{th} is a measure for the amount of heat required to raise the NTC's mean temperature by 1 K. C_{th} is stated in mJ/K.

The relationship between heat capacity, dissipation factor and thermal cooling time constant is expressed by:

$$C_{th} = \delta_{th} \cdot \tau_c \quad (\text{formula 5})$$

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3.1.6 Thermal cooling time constant τ_c

The thermal cooling time constant refers to the time necessary for an unloaded thermistor to vary its temperature by 63.2% of the difference between its mean temperature and the ambient temperature.

τ_c depends to a large extent on the component design. The values of τ_c specified in this data book have been determined in still air at an ambient temperature of 25 °C.

The NTC thermistor is internally heated to 85 °C to measure subsequently the time it requires to cool down to 47.1 °C at an ambient temperature of 25 °C. This adjustment to the ambient is asymptotic and occurs all the faster, the smaller the device is.

3.1.7 Ageing and stability

At room temperature the polycrystalline material shows solid-state reactions which lead to an irreversible change in the characteristics (usually resistance increase, change of B value etc).

Physical reasons for this may be thermal stress causing a change in concentration of lattice imperfections, oxygen exchange with the environment (with unprotected, non-glass-encapsulated thermistors) or diffusion in the contact areas of metallized surface contacts. At low temperatures these reactions slow down, but at high temperatures they accelerate and finally decline with time. To enhance long-term stability, our NTC thermistors are subjected to an ageing process directly after manufacture.

4 How to determine the ordering code for inrush current limiters

A component and the packing in which it is to be delivered are unambiguously defined by the ordering code (part number), which has up to 15 digits.

For all NTC thermistors the ordering codes are explicitly stated (together with the corresponding tolerance and/or packing variants) in the data sheets.

Should there be any doubt about the coding system, however, then it is better to order the component using a plain text description (i.e. without a code). In this case, the translation into the part number, which is required for internal handling of the order, will be done by us. The components are delivered by part numbers only.

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Ordering code structure for inrush current limiters, S series

Example: Nominal diameter 11.5 mm, $R_{25} = 8 \Omega \pm 20\%$, bulk packing

B57	236S	0	809	M	0	00
NTC thermistor						
ICLs, S series: 153S = S153 series, nominal $\varnothing$ 8.5 mm 235S = S235 series, nominal $\varnothing$ 9.5 mm 236S = S236 series, nominal $\varnothing$ 11.5 mm 237S = S237 series, nominal $\varnothing$ 15 mm 238S = S238 series, nominal $\varnothing$ 16 mm 364S = S364 series, nominal $\varnothing$ 21 mm 464S = S464 series, nominal $\varnothing$ 26 mm						
Internal coding						
Resistance at rated temperature (25 °C): Examples: $809 = 80 \cdot 10^{-1} \Omega = 8 \Omega$ $100 = 10 \cdot 10^0 \Omega = 10 \Omega$						
Resistance tolerance: M = $\pm 20\%$						
Internal coding						
Packaging codes: 00 = Bulk 51 = Radial leads, kinked, 360-mm or 500-mm reel 54 = Radial leads, kinked, Ammo packing						

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Ordering code structure for inrush current limiters, P series

Example: Nominal diameter 13 mm, $R_{25} = 4 \Omega \pm 20\%$, bulk packing

B57	211P	0	409	M	3	01
NTC thermistor						
ICLs, P series: 211P = P11 series, nominal $\varnothing$ 13 mm 213P = P13 series, nominal $\varnothing$ 14.5 mm 127P = P27 series, nominal $\varnothing$ 31 mm						
Internal coding						
Resistance at rated temperature (25 °C): Examples: $508 = 50 \cdot 10^{-2} \Omega = 0.5 \Omega$ $409 = 40 \cdot 10^{-1} \Omega = 4 \Omega$ $100 = 10 \cdot 10^0 \Omega = 10 \Omega$						
Resistance tolerance: M = $\pm 20\%$						
Internal coding						
Packaging codes: 01 = Bulk 41 = Radial leads, kinked, Ammo packing 51 = Radial leads, kinked, 500-mm reel						