

PTC Thermistors

Application notes

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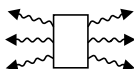
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1 Application notes

As to their possibilities of application, PTC thermistors can be divided in the following manner:

a) by function

Directly heated PTC thermistor



Heat is generated in the PTC thermistor

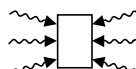


Power PTC thermistors

Applications where the electrical resistance is primarily determined by the current passing through the thermistor.

TPT0324-A-E

Indirectly heated PTC thermistor



Heat is supplied from outside



PTC temperature sensors

Applications where the electrical resistance is primarily determined by the temperature of the medium surrounding the thermistor.

TPT0324-B-E

b) by application

Power PTC thermistors	Sensors
Fuse: – Short-circuit – Overcurrent protection	Limit temperature: – Motor protection – Overtemperature protection
Switch: – Motor start – Switching	
Heater: – Heating elements	
Level sensor: – Point level sensors	
Resistor: – Inrush current limiters	

1.1 PTC thermistors for overcurrent protection

Ceramic PTC thermistors are used instead of conventional fuses to protect loads such as motors, transformers, etc. or electronic circuits against overcurrent. They not only respond to inadmissibly high currents but also if a preset temperature limit is exceeded. Thermistor fuses limit the power dissipation of the overall circuit by increasing their resistance and thus reducing the current to a harmless residual value. In contrast to conventional fuses, they do not have to be replaced after elimination of the fault but resume their protective function immediately after a short cooling-down time.

As opposed to PTC thermistors made of plastic materials, ceramic PTC thermistors always return to their initial resistance value, even after frequent heating/cooling cycles.

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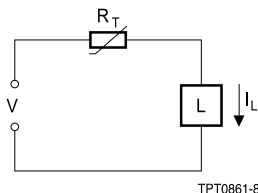


Figure 1
PTC thermistor fuse connected in series with the load
 I_L Load current

1.1.1 Operating states of a PTC thermistor for overcurrent protection

Figure 2 illustrates the two operating states of a PTC fuse. In rated operation of the load the PTC resistance remains low (operating point A_1). Upon overloading or shorting the load, however, the power consumption in the PTC thermistor increases so much that it heats up and reduces the current flow to the load to an admissible low level (operating point A_2). Most of the voltage then lies across the PTC thermistor. The remaining current is sufficient to keep the PTC in high-resistance mode ensuring protection until the cause of the overcurrent has been eliminated.

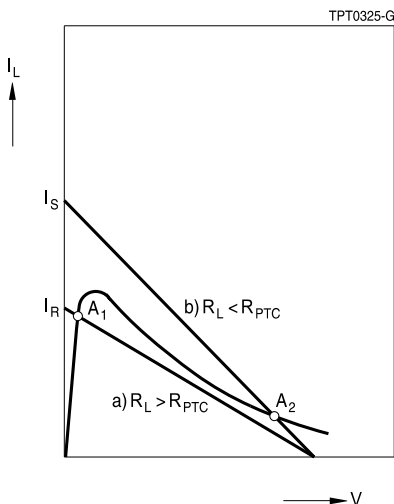


Figure 2
Operating states of a PTC thermistor for overcurrent protection

a) Rated operation

b) Overload operation

R_L Load resistance

I_S Switching current

I_R Rated current

R_{PTC} PTC resistance

1.1.2 Considerations on the rated current I_R

An essential parameter for the function and selection of a PTC thermistor fuse is the rated current. It is mainly a function of:

- PTC dimensions,
- PTC temperature,
- PTC resistance,
- heat dissipation.

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Very often high rated currents are required. Higher rated currents with unchanged resistance are obtained through larger thermistor dimensions (see figure 3) or by raising the reference temperature. Favorable conditions for high rated currents can be achieved by making the best possible use of the cooling effect of the environment. The manufacturer contributes to good heat dissipation by producing the thermistors with large surfaces and making them as thin as possible. The user can enhance the heat dissipation effect by further measures (e.g. cooling fins) so that protective ratings of more than 200 W per component can be achieved.

Another mechanism for controlling the rated current is the PTC resistance itself. To keep the difference between rated and switching current as small as possible, PTC thermistor fuses are only produced in narrow resistance ranges. In practice this leads to PTC types with tolerances of 25% and tighter so that the protective function is also possible in applications with only slight differences in current between rated operation and overload.

Another quantity affecting the rated current is the ambient temperature at which the PTC thermistor is operated. Figure 4 illustrates this relationship. An increase in ambient temperature means that the PTC thermistor reaches the temperature causing it to trip with much less power consumption. A cooler environment has the opposite effect, i.e. power consumption and rated current rise.

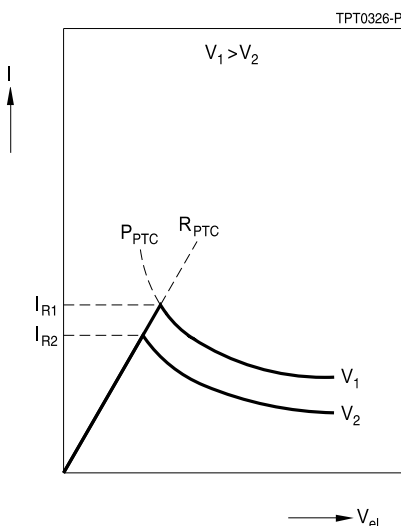


Figure 3
Influence of the PTC volume V on the rated current at given resistance R_{PTC}

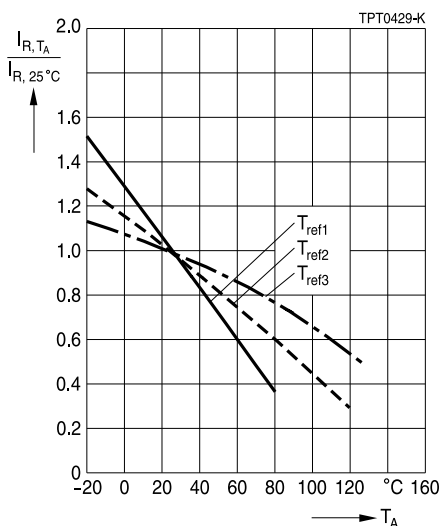


Figure 4
Standardized rated current I_R versus ambient temperature T_A (measured in still air)
Parameter: $T_{ref1} < T_{ref2} < T_{ref3}$

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1.1.3 Switching time versus switching current

The dynamic heating behavior of the PTC thermistor is determined by the specific heat capacity of the titanate material, which is approx. 2.7 Ws/Kcm^3 . At short switching times – less than 5 s with commonly used overcurrent protection devices – heat dissipation through the surface and lead wires is virtually negligible. Almost the entire electrical dissipation is consumed to heat up the ceramic material, to increase the temperature above the reference temperature and thus to produce a stable operating point on the R/T characteristic. When dissipation increases with rising difference between device temperature and ambient, only a small amount of excess energy remains for heating the component and the result is the switching time curves as a function of switching current shown in figure 5.

TDK offers a wide selection of PTC thermistors for overcurrent protection covering rated voltages up to 1000 V (with rated current 8 mA) and rated currents up to 2.1 A (rated voltage 12 V). Many years of volume production and positive experience gained with the long-term features of overcurrent protection components in practice have verified the particularly high safety and reliability of these ceramic PTC thermistors.

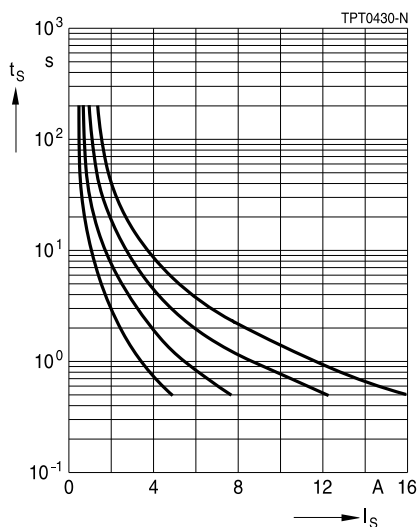


Figure 5

Switching times t_s of some PTC thermistors (parameter: different geometries) versus switching current I_s (measured at 25°C in still air)

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1.1.4 Selection criteria

In circuit design, the following considerations should be borne in mind when selecting a PTC thermistor as overcurrent protector.

Maximum voltage

During normal operation only a small part of the overall voltage is applied to an overcurrent protection PTC thermistor in series with a load. When it responds, i.e. when it goes high-resistance, it has to handle virtually the entire supply voltage. For this reason the thermistor's maximum operating voltage $V_{\max}$ should be chosen sufficiently high. Possible supply voltage fluctuations must also be allowed for.

Rated current and switching current

The next thing is to find a PTC thermistor with sufficiently high rated current (that current at which the thermistor will under no circumstances turn off) within the suitable voltage class. So you should consider whether the overall layout of the circuit can handle the increased power for the short time until the PTC thermistor reduces it. Here a worst-case estimate is necessary. Rated and switching currents depend on the ambient temperature. So, as the worst case for the rated current, the maximum permissible ambient temperature for the application should be taken, and for the switching current the lowest possible ambient temperature.

Maximum permissible switching current at $V_{\max}$

When considering possible situations in which the PTC thermistor is to give protection, it is necessary to examine whether there will be conditions in which the maximum permissible switching current will be exceeded. This will generally be the case when it is possible for the load to be short-circuited. In the data sheets a maximum permissible switching current $I_{S\max}$ is stated for the maximum operating voltage $V_{\max}$. Overloading the PTC thermistor by too high a switching current must be avoided. If there is indeed such a risk, e.g. through frequent shorting, it can be countered by connecting a resistor in series with the PTC thermistor.

Selection of reference temperature

TDK offers PTC thermistors for overcurrent protection with reference temperatures of 80, 120, 130 and 160 °C. The rated current depends in turn on this reference temperature and the disk diameter of the thermistor. In trying to find an attractively costed solution, one could decide on a component with high reference temperature and a small disk diameter. In this case it is necessary to check whether the high surface temperature of the thermistor in the circuit could lead to undesired side-effects. The circuit board material, the configuration of the surrounding components and the spacing from any enclosure as well as any sealing compounds must all receive due attention.

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Environmental effects

If any washing solutions other than those suggested in this data book are used (e.g. isopropyl alcohol), if there is any contact with chemicals or use of potting or sealing compounds, all due care should be taken. The reduction of the titanate ceramic that can be caused by chemical effects on the surface of the thermistor and the resulting formation of low-resistance conducting paths or the altered thermal relations in the sealant can lead to local overheating of the PTC thermistor and thus to failures.

1.1.5 Circuit configuration

PTC thermistors can be used for versatile protection applications. The circuit diagram below (see figure 6) shows the simplest circuit configuration for protecting a transformer.

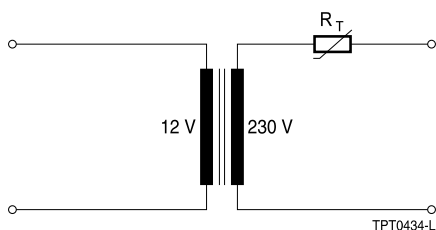


Figure 6
Simplest circuit for
protecting a transformer
(primary side)

PTC thermistors are also employed for input protection of measuring instrumentation up to 1000 V, for household appliances (in particular small equipment) and for vehicle motor and air fan protection.

1.2 PTC thermistors for telecommunication applications

A special case of overcurrent protection are PTC thermistors for telecommunication applications. Overvoltage and current in telephone lines can result from surges due to direct lightning strikes, induction between power lines and phone lines as well as direct contact between power lines and phone lines.

Many international specifications and recommendations (IEC, ITU-T) now stipulate full functionality of equipment after testing for a variety of energy levels whilst safe failure is still permitted for higher levels. The solution here is to use resettable devices such as PTC thermistors, which resume their initial resistance once the disturbance has subsided.

The selection criteria for PTC thermistors for telecommunication applications are the same as applied to standard overcurrent protection PTC thermistors. In addition the following should be considered.

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1.2.1 Rated current and temperature

The PTC thermistor is primarily used to protect the switching equipment against fault current through direct contact with a power line (power contact) or an induced surge of short duration and low voltage from a neighboring line (power induction). For obvious reasons, the rated current of the PTC thermistor should be kept as low as possible so that the protection responds quickly to overcurrents.

The rated current should typically be slightly higher than the operating current of the system to be protected at the normal operating temperature. Here the dependence of the rated current on the temperature of the ambient must be considered. You can find this dependence in the data sheets.

1.2.2 Duration of disturbance – voltage classes

An aspect that is too often neglected is the duration of the power contact. Such disturbances can go undetected for many hours, meaning that the PTC thermistor could be held in the high resistance condition exposed to the line voltage for an indefinite period. TDK PTC thermistors for telecommunication applications are able to pass a fault condition of at least 265 V AC and can withstand this condition for a long time.

1.2.3 Imbalance on the line – resistance of PTC thermistor

For most telecom applications the balance between the tip and ring (often referred to as longitudinal balance) is essential. A figure must be assigned to the balance between the line resistances that must apply initially and, after a short cooling period, after operation. Typically 1 Ω is demanded on delivery, which should also apply throughout the service life of a system. TDK therefore offers matched or binned PTC thermistors for telecommunication applications where the resistance within one pack unit is selected so that the maximum difference is defined.

As opposed to PTC thermistors made of plastic materials, ceramic PTC thermistors always return to their initial resistance value, even after frequent heating/cooling cycles.

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1.3 PTC thermistors for time delay and switching applications

These PTC thermistors are used when a load in series with the thermistor has to be switched off after a time delay and when switching occurs frequently.

Figure 1 and 7 show a typical configuration of a PTC thermistor in series with a load and the delayed drop of the load current. The switching function of the PTC thermistor consists in limiting the current flowing through the load at high operating voltages after the thermistor has heated up. Differences in current of a factor of 1000 are the rule here. The switching time t_s can be approximated as follows:

$$t_s = \frac{C_{th} \cdot V \cdot (T_{ref} - T_A)}{P}$$

T_{ref} Reference Temperature of PTC thermistor

T_A Ambient temperature

C_{th} Heat capacity of PTC thermistor

V PTC thermistor volume

P Switch-on power of PTC thermistor

This shows that the switching time can be influenced by the size of the PTC thermistor, its reference temperature and the power supplied. Manufacturing techniques allow a variation of the switching time in a wide range. Switching times are lengthened by increasing the volume or the reference temperature; high power consumption by the PTC thermistor, on the other hand, results in short switching times. The graph in figure 9 shows the switch-off behavior for different levels of current consumption.

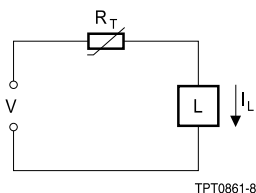


Figure 7

Typical configuration of a PTC thermistor for time delay

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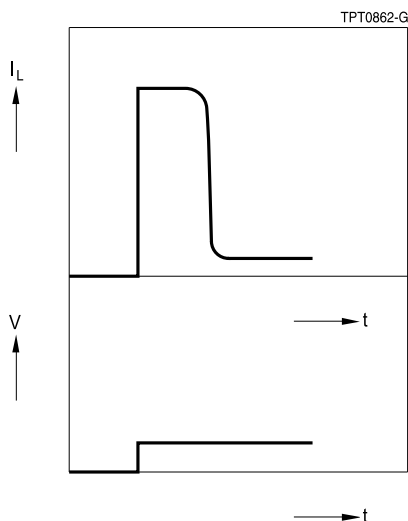


Figure 8
Typical delay of the load current I_L

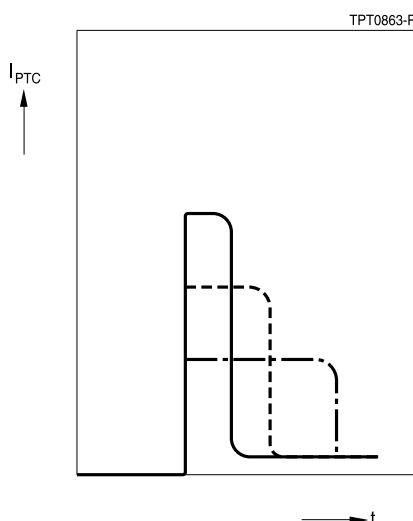


Figure 9
Typical switch-off behavior of a PTC thermistor

A typical application for switching PTCs is the preheating of electrodes in energy-saving lamps or fluorescent lamps. Here the PTC is connected in series with the two electrodes of the lamp (see figure 10). When the rectified line is applied to the circuit the PTC is cold and low resistance. The lamp voltage is below the ignition voltage and the flowing current heats the electrodes and the PTC. After a certain period the PTC will switch, the voltage across the lamp will exceed the ignition voltage and the lamp will start to burn. Preheating of the electrodes lengthens the life of the lamp significantly. A full range of standard devices is available and custom engineered samples can be rapidly created for special lamp designs.

Switching PTCs can also be used as a power resistor for loading capacitors, for example in power supplies or in control units of production equipment. Depending on the applied voltage and the capacitance of the capacitor, one or more PTCs in parallel will be necessary to load the capacitor. In contrast to fixed resistors, the PTC also offers protection against a possible shortcircuit in the capacitor. TDK PTCs in housings are recommended in case of a large number of switching cycles.

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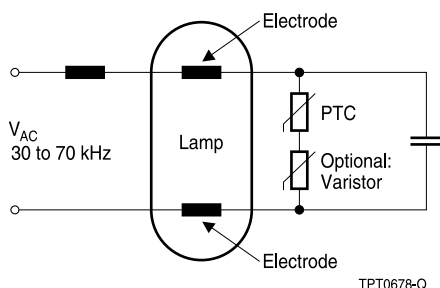


Figure 10
Principle circuit diagram for the preheating of electrodes in energy-saving lamps or fluorescent lamps

1.4 PTC thermistors for motor starting

Single-phase induction motors (e.g. in compressors for refrigerators and air conditioners) can effectively be started when an auxiliary coil is used in the starting phase. The auxiliary coil is cut off from the circuit after the starting phase. For this purpose PTC thermistors are employed.

When high voltage is applied to the PTC thermistor, the high current causes the PTC to heat up and eventually the resistance to increase. A high current flows initially (starting phase) and then decreases in relation to the increase in resistance. After the starting phase (at times $\gg t_s$), a low residual current flows through the auxiliary coil.

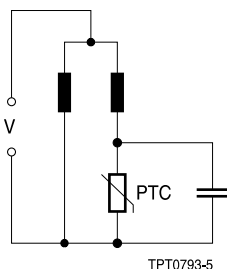


Figure 11
Simple starter circuit for single-phase AC motors
The PTC thermistor is used for delaying the switch-off of the starter auxiliary winding (after the motor has accelerated) to protect the winding from damage.

A wide range of types including some encased models is available for motor start applications. TDK motor start thermistors have been designed for a large number of switching cycles (>100000) at high starting powers.

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1.5 PTC thermistor sensors

A PTC thermistor is used as a sensor when the influence of environmental conditions (e.g. temperature) on the electrical characteristics is monitored.

1.5.1 Level sensors

A thermistor heated with a low voltage of approx. 12 V responds to a change in external cooling conditions by changing its power consumption. At constant voltage the power consumption is hence a measure for the dissipation conditions. With increasing dissipation the thermistor cools down and the current rises due to the positive temperature coefficient.

A marked increase in current occurs when a PTC thermistor heated in air is immersed into a liquid, where a larger amount of heat is dissipated than in air. This feature makes the PTC thermistor an ideal candidate for overflow control in tanks for liquids. TDK offers hermetically sealed (glass or stainless steel case) PTC thermistors for this kind of application.

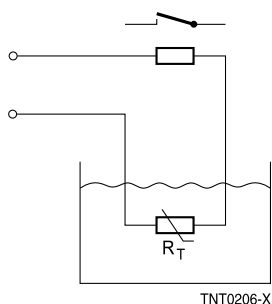


Figure 12
Circuit configuration for liquid level control

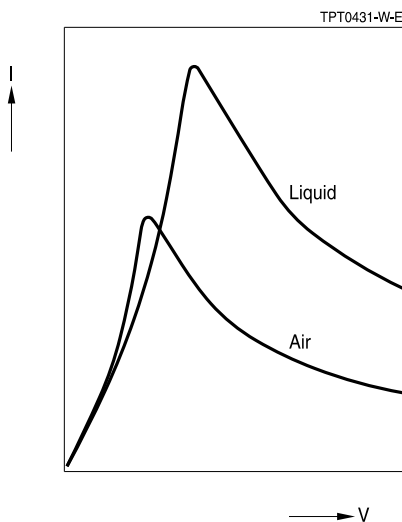


Figure 13
Current versus voltage in different media
 G_{th} in liquid $>$ G_{th} in air
 G_{th} = thermal dissipation factor

Further applications are:

- Overflow protection for oil tanks (prescribed by the German Technical Inspectorate TÜV)
- Liquid level measurement
- Limit indication (e.g. indicator for too low a water level in the reservoir for the windshield wipers)
- Leakage sensing

1.5.2 PTC sensors for motor and machine protection

PTC thermistors are widely employed as temperature sensors in electrical machines to monitor winding temperature. In this case, the PTC thermistor is wound directly into the winding so that direct thermal contact is produced. TDK offers special types that conform to DIN 44081 and DIN 44082 and that can be designed in with Siemens tripping units.

The abrupt increase in the resistance of the thermistor at high temperatures can be used as a control signal for the tripping unit. To detect the temperature at several phases, thermistors should be connected in series. TDK offers standard single and triple sensor versions as well as custom assemblies. Available sensing temperatures range from 60 to 180 °C.

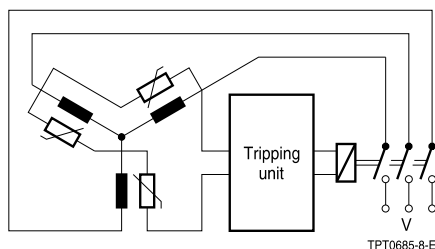


Figure 14
Schematic circuit diagram of the protection of a three-phase electric motor with a triple PTC thermistor sensor assembly

1.5.3 PTC thermistors as limit temperature sensors

With PTC thermistors as temperature sensors only the steep region of the R/T characteristic is used. The resistance of the PTC thermistor is to be regarded as a function of the ambient temperature [$R_{PTC} = f(T_A)$].

The precondition for this relationship between resistance and ambient temperature is that self-heating and/or the varistor effect are excluded. This means that these PTC thermistors must be operated in the lowest possible field strengths. To enable a fast response, thermistor sensors have especially small dimensions. High control accuracy is achieved by using materials with an extra steep resistance/temperature characteristic.

Limit temperature measurement for industrial applications

A PTC thermistor can be used effectively to detect whether a temperature limit in industrial equipment, liquids, etc. is exceeded. The PTC thermistor is mounted in thermal contact with the medium that has to be protected from overheating. When the rated temperature limit of the medium is reached, the resistance of the PTC thermistor increases abruptly. In connection with a control unit, this signal can be used to automatically switch off the power supply of a load. TDK offers leaded disks, metal tags, screw-type metal cases as well as surface-mounted devices.

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Limit temperature sensor for power semiconductors

Power semiconductors, for example in DC/DC converters or in dimmers for lighting, produce a lot of heat in relation to their (small) dimensions. If heat transfer is restricted or impeded, for instance by fan failure or excessive ambient temperature, this can quickly lead to damage or destruction of the semiconductor or surrounding components. A PTC thermistor sensor makes it possible to intervene in operation of the power stage directly and with a measured response in the event of excess temperature. When the temperature exceeds the temperature limit of the semiconductor (e. g. a power transistor or thyristor), the resistance of the thermistor increases, resulting in a reduction of the power applied to the semiconductor. This prevents the semiconductor from overheating.

The thermistor must be thermally coupled to the semiconductor and placed in its current control circuit. For this purpose TDK offers SMD PTC thermistor versions.

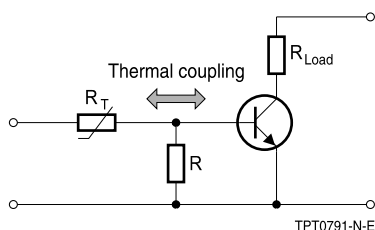


Figure 15
Principle circuit diagram for the protection of power semiconductors by a PTC thermistor limit temperature sensor

1.6 PTC thermistors as heating elements

The use of PTC thermistors is not confined to switching and current and temperature sensing applications. They are also ideal as heating elements because of their specific R/T characteristic.

The positive R/T characteristic means that electric power consumed is automatically adapted to the ambient thermal conditions. At an ambient temperature significantly lower than T_{ref} , i.e. with good heat transfer, the thermistor has low resistance and consumes a relatively large amount of power. If the ambient temperature is significantly higher than T_{ref} or heat transfer is restricted, the resistance of the thermistor rises rapidly and power consumption is limited to a very low value.

Thanks to these self-regulation properties, heating devices based on PTC thermistors can generally dispense with control and regulating components as well as overtemperature protection. So PTC thermistor heating elements are used wherever measurement and regulating equipment as well as heating devices must be housed in tight confines. There are no glowing parts, because the maximum surface temperature is limited by the R/T curve.

In heating applications the PTC thermistors are operated directly at the available voltage without a series resistance, preferably in the low-resistance section of the R/T characteristic (see figure *), since particularly high heating power is achieved in this section of the curve. To make use of this advantage, it is important to create conditions that will not cause the PTC thermistor to raise its resistance. This is ensured with extremely thin PTC thermistors by increased heat transmission from the surface. To this end, the PTC thermistor is placed between heat-emitting solid bodies to optimize heat flow from the thermistor to the environment to be heated. Here, symmetrically ther-

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mal decoupling is of great advantage.

Special care has to be taken when PTC thermistors are used in potted circuits. The high thermal resistance of potting materials can very much impair heat transmission so that the PTC thermistors could heat up to a critical temperature level.

In PTC thermistors operated at line voltage, steep temperature gradients and sometimes high operating temperatures are generated in the heating-up phase. In these cases soldering should be avoided since the solder joints may fatigue. The devices are offered by the manufacturer with a metallized surface for clamp contacting, which guarantees favorable thermal decoupling.

Dimensioning PTC thermistors:

The electrically absorbed power of the PTC equals the thermal dissipated power:

$$\frac{V^2}{R_{\text{PTC}}} = \frac{(T_{\text{surf,PTC}} - T_{\text{A}})}{R_{\text{th}}}$$

R_{th} thermal resistance in K/W

$T_{\text{surf,PTC}}$ surface temperature of PTC thermistor

T_{A} ambient temperature

The thermal resistance R_{th} depends on the dimensions and the thermal conductivity of the PTC and the contact electrodes, as well as the heat transfer coefficient of the surrounding media (e. g. air). For maximum heat output, the thermistor must be mounted in a plane configuration so that minimum thermal resistance is obtained. The following equation can be generally applied to calculate the thermal resistance R_{th} :

$$R_{\text{th}} = \sum_i \frac{t_i}{A_i \lambda_i} + \sum_j \frac{1}{A_j \alpha_j}$$

α heat transfer coefficient in W/(cm² · K)

A cross-sectional area of material transferring heat

t layer thickness in cm

λ thermal conductivity in W/(cm · K)

This means that the power dissipation of a heating PTC depends not only on the properties of the PTC thermistor itself but also on the heat transfer coefficient and geometry of the clamping contact, as well as on the surrounding medium and its temperature. This should be taken into account in the design of the heating assembly and for the selection of the PTC.

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Selection criteria for PTC heating thermistors:

Operating voltage

This is usually between 12 V and 500 V.

Surface temperature T_{surf}

T_{surf} varies from 40 °C to 280 °C. The higher the surface temperature selected, the greater the power that can be dissipated. A high surface temperature leads to considerable thermal stress on the entire design if thermal dissipation is poor.

Dimensions

PTC thermistors are available in circular and rectangular designs. The surface area of the thermistor depends on the heat output required. Its thickness depends on the operating voltage used in the application. A thickness of 1.1 mm is recommended for 12 V applications, 2 mm to 5 mm for 230 V up to 500 V applications. The thicker the thermistors, the lower the field strength at the components and thus the more reliable the application, e.g. in handling voltage peaks in the line.

A wide range of sizes is offered in order to reach the most effective solution.

Resistance

As the resistance of PTC thermistors varies with applied voltage, the resistance R_{min} at the rated voltage is given. This defines the maximum current flowing as the thermistor heats up: $I_{\text{in}} = V / R_{\text{min}}$. I_{in} determines the heating characteristics of the PTC thermistor. R_{min} varies depending on design.

If the heating output of one heating PTC thermistor is not sufficient for a certain application, several PTCs can be mounted together, i.e. if the thermistors are electrically connected in parallel. In this way output power up to 5 kW may be achieved in a compact design.

Application examples for heating thermistors:

Automotive

- Additional cabin heating
- Diesel fuel preheating
- Diesel fuel filter heating
- Windshield washer nozzle heating
- Heating of crank case venting system

Domestic

- Fan heaters, e.g. bathroom heaters
- Electric hair curlers
- Insecticide and perfume vaporizers
- Bimetal heaters for door latches of washing machines
- Oil preheating in oil burners
- Thermal actuators for liquid dispensers and thermostats

Others

- Glue guns
- Plastic film welders