NTC THERMISTOR SENSOR PERFORMANCE

Accuracy, Interchangeability, Beta Tolerance, Tolerance Comparison, Stability, Drift, and Moisture Induced Failure

APPLICATION NOTE

When designing the best temperature probe for a specific application, the process is a series of choices to meet your application requirements while juggling key parameters. Selecting the best temperature sensor is a critical part of the process. The following is a discussion of key performance characteristics that should be considered.

I. Accuracy

- How exactly a specific temperature is reflected by a specific resistance.
- Calibration at a specific temperature can approach ±0.01˚C (≈0.1%).
- Usually specified as ±1%, ±5%, ±10% or ±25% at a temperature (point-matching).
- Typically specified at 25˚C.

Accuracy can be confusing. In most electronic devices accuracy refers to how closely a device reflects actuality. To accurately define this ability for sensors, you must be able to prove traceability to an absolute.

The absolute in the case of thermistors is temperature as it is defined by ITS-90, using fixed points cells and transfer standards. It is generally accepted that temperature itself is defined no more accurately than ±0.002˚C between fixed points. So, by extension it is unreasonable to assume any temperature sensor can realize accuracy greater than this value. The accuracy of calibration of the temperature sensor itself is the limiting factor. Thus, a part measured in a bath using electronics with a total system error of ±0.01˚C could be considered no more accurate than ±0.01˚C. (Metrology rules typically allow that with a system error of ±0.01˚C claimed accuracy is four times greater.)

So, a commercial temperature sensor cannot provide accuracy greater than ±0.002˚C. **Thermistors**, over their measurement range, are some of the most accurate sensors available.

II. Interchangeability

- How closely a specific thermistor tracks a published resistance curve over a span of temperature.
- Instrument manufacturers include interchangeability error in overall accuracy statements.
- TE's standard interchangeability values are ±0.2, ±0.1, and ±0.05˚C over the temperature range of 0 to 70˚C.

Interchangeability is easy to understand. First, think of the published resistance curve as the absolute of accuracy. Then interchangeability becomes the deviation from this absolute. Sometimes interchangeability is also referred to as accuracy, but the two terms should be differentiated from one another.

TE thermistors are typically rated over the range of 0 to 70˚C for their tightest tolerance.

The advantage of interchangeable parts is clear; one part may be interchanged for another with no degradation in performance. Prior to interchangeable temperature probes and components, each sensor assembly had to be calibrated in circuit after replacement. This cost is eliminated entirely by using interchangeable parts.

III. Beta Tolerance

- Beta is an indicator of the shape of the resistance versus temperature curve.
- Beta tolerance indicates the amount of deviation in the overall R vs. T curve.
- Must be added to the accuracy of a point-match thermistor.
- Beta tolerance for interchangeable parts is included in the overall interchangeability value.

Beta tolerance is often seen in literature as a definition of a thermistor curve. The actual formula for Beta is:

$$\beta = \ln(R_1/R_2) \,/\, (1/T_1 - 1/T_2)$$

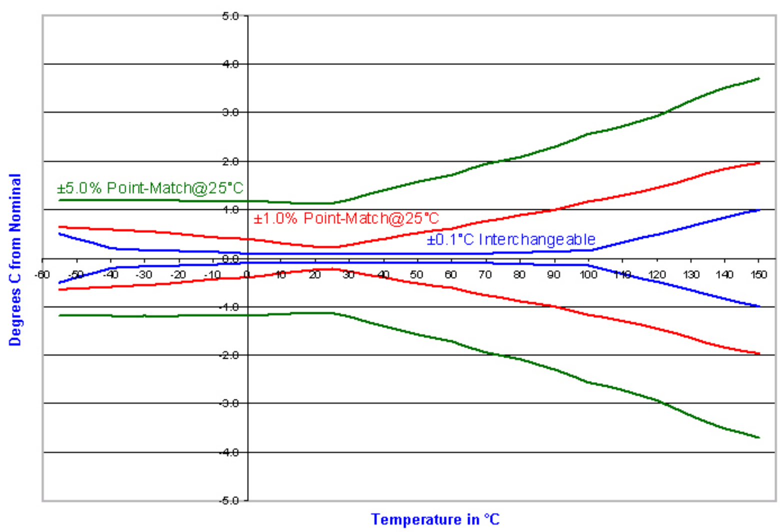
where R1 is the resistance of a part at a temperature T1 and R2 is the resistance of the part at another temperature T2. In the formula, these temperatures must be Kelvin (˚C + 273.15).

Typically, Beta is shown over a temperature range of 0 to 50˚C or some other specified range. Variations in the temperature points will cause some variation in the results, so it is important to compare Beta values over the same range when trying to match a part's curve.

Beta tolerance describes how closely a part's actual curve tracks the nominal curve defined by its Beta value. This value is most often used when describing point-matched parts. For example, a part may be shown as having a tolerance of ±10% @ 25˚C with a Beta tolerance of 5%. This tolerance must be applied to the nominal Beta value and calculated backwards to determine the actual error at points other than 25˚C.

Interchangeable thermistors incorporate Beta tolerance into the specification. There is effectively no Beta tolerance on an interchangeable part. Its accuracy is defined by its interchangeability to the absolute nominal curve.

IV. Tolerance Comparison



This chart compares the tolerance differences between an interchangeable thermistor and two point-matched thermistors.

The blue lines show the interchangeable tolerance band of a ±0.1˚C part. Notice the straight line between 0 and 70˚C indicating the range of tightest interchangeability. There are steps outwards at -40, 0, 70, and 100˚C.

Contrast this with the red and green lines that show their tightest tolerances at 25˚C with widening tolerances (the result of Beta tolerance) above and below 25˚C.

There are two common ways to classify tolerance. The most widely used is percentage deviation from nominal. This is almost exclusively used for point-matched parts. For example, a 10,000-ohm part at 25˚C with a ±5% tolerance has a maximum resistance error of 500 ohm. A measurement using one of these thermistors at exactly 25˚C could give a resistance reading between 9,500 and 10,500 ohms. Using the sensitivity of the curve (defined as a percent change per degree) you can calculate the ohms change per degree or the temperature error for a specific thermistor. In this example, if we assume a "B" mix thermistor (with a –4.4%/˚C sensitivity @ 25˚C), you can calculate ohms per degree by:

$$\text{Nominal resistance x ohms change/degree} = 10{,}000\ \Omega \text{ x } -0.044/^{\circ}\text{C} = -440\ \Omega/^{\circ}\text{C}$$

Dividing 500 ohms by –440 ohms gives you a –1.136˚C error @ 25˚C for a +5% deviation in resistance. The green line in the graph above represents this. Alternately you can do all calculations in percent: 5% divided by –4.4%/˚C = -1.136˚C.

For interchangeable parts, calculations are often done in temperature converted to ohms rather than percentage. In the chart above a ±0.1˚C interchangeable part with a –4.4%/˚C sensitivity (440 □/˚C) has a resistance error of ±44 ohms, significantly better than the ±500 ohms shown by the 5% tolerance part.

Recognizing the difference in overall temperature tolerance allows you to choose the best sensor for a specific application. You might choose a tight tolerance sensor to allow extra error in your instrumentation.

V. Stability

- Variation over time in the resistance of a sensor.
- Influenced primarily by prolonged elevated temperature exposure.
- Varies based on sensor fabrication methods and encapsulation materials.
- Glass-encapsulated pressed disks and glass beads are most stable.

While specifying the correct tolerance is important, you must also consider the stability of the temperature sensor for each specific application. Specifying a tight tolerance part does not do any good if the part quickly drifts out of tolerance because of excessive shift at its operating temperature.

Thermistors shift resistance upward over time. How great this shift is depends on construction methods and encapsulant. Typically, all thermistors are stable at room temperature and below. As exposure temperature increases so does drift.

Temperature cycling, while causing other mechanical stresses during temperature changes, primarily affects stability during the high temperature cycles. For example, if a part in an application cycles between 25 and 100˚C with equal times at each temperature, then after a year of use the total drift will be similar to 100˚C use for six months.

Pressed disk components are more stable than cast chip thermistors.

MEAS 55000 series thermistors, while more stable than MEAS 44000 series parts, share the same electrode system and differ only in encapsulation – glass vs. epoxy coating. This simple difference improves the stability significantly. MEAS 45000 and 46000 series parts use a proprietary electrode system to offer excellent stability available for pressed disks.

Glass-coated bead thermistors match or exceed the stability of MEAS 46000 series thermistors. Bead-in-glass probes are stable sensor platforms.

VI. Pressed Disk Drift Characteristics

Drift – 10 Month Data

Operating Temperature	Epoxy-Coated	Glass-Coated	Glass-Coated Super-Stable
0˚C	<0.01˚C	<0.01˚C	<0.01˚C
25˚C	<0.01˚C	<0.01˚C	<0.01˚C
70˚C	not available	not available	<0.01˚C
100˚C	0.20˚C	0.12˚C	0.02˚C
150˚C	1.50˚C	0.15˚C	0.05˚C
200˚C	not applicable	0.20˚C	0.22˚C

The data in the chart above shows increased drift over time with elevated temperatures. Note that even a 0.2˚C drift at 100˚C for TE epoxy-coated pressed disks is one of the best stability measurements in the industry for epoxy-coated parts.

Note also that at 150˚C MEAS 55000 series glass-coated thermistors offer a ten-fold improvement in stability over MEAS 44000 series parts.

Finally, MEAS 46000 glass-coated super-stable parts offer some of the best stability performance available for any type of temperature sensor.

Drift – 100 Month (8 Years) Data

Operating Temperature	Epoxy-Coated	Glass-Coated	Glass-Coated Super-Stable
0˚C	<0.01˚C	not available	<0.01˚C
25˚C	<0.02˚C	not available	<0.01˚C
70˚C	not available	not available	<0.01˚C
100˚C	0.32˚C	not available	0.03˚C
150˚C	not recommended	not available	0.08˚C
200˚C	not applicable	not available	0.60˚C

Note that in the data for 100 months continuous use, the drift is not ten times greater than at 10 months. This reflects the flattening of drift rates over time.

Based on the application, some general recommendations can be made to ensure minimal drift:

Surface mount chips, while one of the most stable in the industry, should be limited to uses under 100˚C, considering the potential for drift and potential errors over time.

Continuous Temperature	Recommended TE Thermistors
<50˚C	Any
70˚C	Any
100˚C	44000, 55000, 45000, 46000, beads, bead-in-glass
125˚C	55000, 45000, 46000, beads, bead-in-glass
150˚C	55000, 45000, 46000, beads, bead-in-glass
200˚C	45000, 46000, bead-in-glass
250˚C	45000, bead-in-glass
300˚C	bead-in-glass probes

Note that in the data for 100 months continuous use, the drift is not ten times greater than at 10 months. This reflects the flattening of drift rates over time.

VII. Moisture Induced Failure

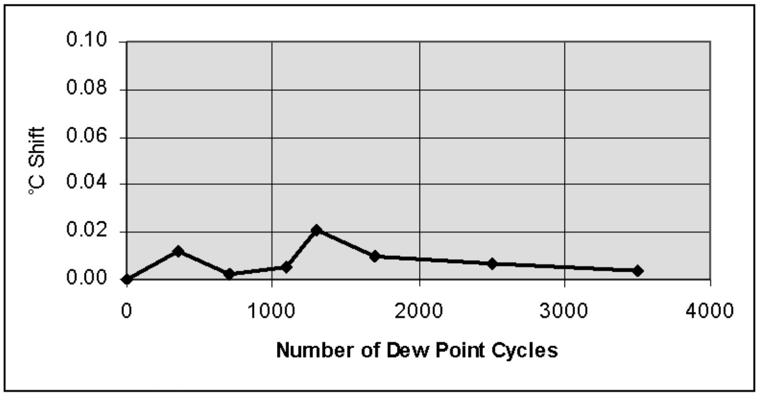
- Moisture compromises encapsulating material.
- Interacts with impurities near electrodes.
- Effectively “electroplates” a short circuit across ceramic.
- Hermetic glass seals eliminate this failure.

Moisture induced failure is the greatest cause of failure in thermistors. This type of failure is often difficult to pinpoint in an application. Moisture failures can occur in almost any epoxy-coated component or any probe configuration using epoxy-coated parts (except probes using hermetic seals).

Moisture induced shift is always downward in resistance. This shift continues as the electrode material continues to plate over the ceramic until the part completely short circuits. What makes this difficult to pinpoint is that drying the part will sometimes eliminate the downward shift. Sometimes movement or physical shock to the part will break the conductive path (typically very thin), so even shorted parts can appear to recover. However, being aware of these symptoms of moisture failure will help you to troubleshoot failures.

While many design tricks can be used to minimize the potential for moisture induced failure while using an epoxy-coated part, the ultimate solution is simple: switch to a glass-encapsulated thermistor. MEAS 55000 Series glass-coated parts have the same physical size as MEAS 44000 series epoxy-coated parts, making them a suitable solution for this problem.

Moisture Failure Testing



- MEAS 45000 Series parts tested.
- 3500 cycles.
- 11 minutes below dew point.
- 11 minutes at ambient temperature.
- No appreciable shifts.

This chart shows the results of testing that TE performed for a customer application that was experiencing moisture failures in a probe. This was a tubular probe with a pipe fitting. The probe was mounted in a water line used to cool supercomputers. Even though the computers were in a relatively controlled atmosphere, the chilled water running through the lines lowered the internal temperature of the probe below the dew point and effectively sucked moisture from the atmosphere through the epoxy backfill to the tip of the probe. Over time this moisture made its way through the thermistor's epoxy coating and induced failure.

TE fabricated two sets of new probes to test. One set consisted of the original probe now containing a MEAS 45000 Series glass-coated thermistor instead of an epoxy-coated part. The second set used a similar probe style with the addition of a hermetic seal at the rear of the probe. After 3500 testing cycles, no moisture failures were seen in the probes containing the glass-coated thermistors.

MEAS 45000 Series thermistors were used at the time of these tests. However, since the release of the MEAS 55000 Series glass-coated, machine manufactured parts, a more cost-effective alternative is available. We now recommend that any underwater probe only use glass-coated thermistors. The initial extra cost of glass-coated parts is a small tradeoff for the long-term confirmation of no moisture failure and possible loss of revenue.

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TE CONNECTIVITY

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