Standards Defining Temperature Sensors

Your Host and Presenter

Host
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- 24 years in sales and marketing of custom designed made-to-order products for the industrial and biotech markets.

Presenter
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- 30 years experience in temperature measurement with RTDs and thermocouples in the aerospace, industrial, and laboratory markets.

Topics Covered Today

Why do I care about standards?
Resistance Temperature Detector (RTD) standards
- RTD history
- Common standards
- Uncommon standards
ASTM E20
Thermocouple Standards
Other thermometer types
- ASME B40.9
Thermowell Standards
- ASME PTC 19.3 TW-2010
- ASME B16.5 flange
- ASME B16.11 socket weld and threaded fittings
ASME-BPE
3A Sanitary Standards
The RTD (resistance temperature detector) was first described in 1871. In the US the oldest patent I could find was from 1922 and it was for an improvement.

The oldest evidence of a standard for RTDs was suggested by Hugh Longbourne Callendar in 1899 in which he identified platinum as the best metal to use. He used the ice point and boiling points of water and sulphur for calibration.

Today the ASTM E20 committee meets twice a year to update and write standards that define and control temperature measurement.
The list of standards covers every type of sensor from RTDs and thermocouples to non-contact types and also any new technology.

Within the subgroup resistance thermometers, there are further standards that cover testing, accuracy verification, materials of construction, and performance. Of these, the ASTM E1137 is the one that covers the platinum resistance thermometer.

In addition, the IEC standard covers performance parameters such as hysteresis and time response.
RTD Standards (USA)

ASTM E1137
- Similar to IEC 60751, interchangeability tolerances are smaller
- R vs. T tables

RTD Calibration Standards

IPTS-68 – defines temperature scale and transfer standard, Callendar van Dusen equation
ITS-90 – improved version of IPTS 68
Calibration of RTDs
- ISO/IEC 17025
- ANSI/NCSL Z540-1

Accredited labs follow the IEC 17025 and ASNI/NCSL Z540 standards. This insures a consistent outcome of calibration information.

RTD Standards

Four most important items from the standards - IMO
- Interchangeability
- Insulation resistance
- R vs. T tables
- Lead wire color codes

I pulled four items from the standards that I consider the most important for RTDs. These are necessary to specify a sensor and insure that it is performing correctly for an accurate temperature measurement.
In a perfect world, the RTD manufacturer would build sensors to the nominal values. Unfortunately that is not possible so the standards define a tolerance band called the “interchangeability”. These equations can be used to calculate the interchangeability at any temperature. Note that the temperature ‘t’ is an absolute value in °C. The resultant is the interchangeability in ± °C.

Note that the ASTM standard has slightly tighter tolerances for the two grades of sensors. All RTDs are built with the tightest tolerance at 0°C and as the temperature diverges from 0°C the tolerance increases. The vertical line on the graph represents 0°C and the tolerance on the y axis is expressed in ± °C from nominal.

This is a typical wire wound sensing element. They are about 1” long and 1/16” diameter and are potted inside a stainless steel sheath. If moisture gets into the sheath and/or sensing element the result can be a shorter path for the excitation current and the result is a low resistance measurement.

- Insulation resistance is the first and most important electrical check to make on an RTD
  - Low IR can cause a low temperature measurement due to shunting between the sensing element wires
  - Most IR failures are due to moisture and/or contaminants that may have entered the probe
Insulation Resistance (IR) decreases with an increase in temperature so at room temperature a value much higher than what is really needed for an accurate measurement is required. Industrial Grade RTD accuracy is not significantly affected until the IR drops below a few megohms. The measurement is made by touching one lead of a megohmeter to the leads and the other to the probe sheath. Some Industrial Grade probes are tested to higher levels to insure maximum performance at high temperatures.

RTD Standards

IEC 60751 lead wire colors

Lead wire color may vary by manufacturer

Other less common standards

- JJJG 229 Chinese – similar to IEC
- BS-1904 – similar to IEC
- JIS C 1604 – equivalent to IEC, adds .003916
- Edison Curve 7 - Nickel 120 ohm
- SAMA RC21-4-1996 - .003923, Copper 10 ohm
- US Department of Defense MIL-T-24388 - 0.00392 100
Thermocouple Standards

ASTM E230 / ANSI MC96.1
- Standard and special limits of error tolerances on initial values of emf versus temperature
- Insulation color coding for thermocouple and thermocouple extension wires
- Upper temperature limits
- Negative lead is red

IEC 60584
- Most widely used standard
- Negative lead is white

Other standards
- NBS Monograph 125 and BS 4937 parts 1-7 emf tables
- BS 1843 UK and Czech Republic
- DIN 43710 Germany
- JIS C1610 Japan
- NFC 42-324 France

The biggest difference in the thermocouple standards is how the lead wire colors are designated.

Thermocouple Standards

ANSI and IEC color code differences

<table>
<thead>
<tr>
<th>Thermocouple Type</th>
<th>ANSI</th>
<th>IEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ lead/- lead</td>
<td>+ lead/- lead</td>
</tr>
<tr>
<td>J</td>
<td>White/Red</td>
<td>Black/White</td>
</tr>
<tr>
<td>K</td>
<td>Yellow/Red</td>
<td>Green/White</td>
</tr>
<tr>
<td>T</td>
<td>Blue/Red</td>
<td>Brown/White</td>
</tr>
<tr>
<td>E</td>
<td>Purple/Red</td>
<td>Purple/White</td>
</tr>
<tr>
<td>N</td>
<td>Orange/Red</td>
<td>Pink/White</td>
</tr>
</tbody>
</table>

It is necessary to know the standard that the thermocouple was built to when identifying a thermocouple by color code. There are other standards with different color codes depending on which part of the world you’re in but these are the two most common.

Thermocouple

Limits of error ASTM E230 / ANSI MC 96.1

<table>
<thead>
<tr>
<th>Thermocouple Type</th>
<th>Temperature Range</th>
<th>*Standard Limits greater of</th>
<th>*Special Limits greater of</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>-200°C to 350°C</td>
<td>± 1.0°C or ± 0.75%</td>
<td>± 0.5°C or ± 0.4% **</td>
</tr>
<tr>
<td>J</td>
<td>0°C to 750°C</td>
<td>± 2.2°C or ± 0.75%</td>
<td>± 1.1°C or ± 0.4%</td>
</tr>
<tr>
<td>E</td>
<td>-200°C to 870°C</td>
<td>± 1.7°C or ± 0.5%</td>
<td>± 0.5°C or ± 0.4% ***</td>
</tr>
<tr>
<td>K</td>
<td>0°C to 1180°C</td>
<td>± 2.2°C or ± 0.75%</td>
<td>± 1.1°C or ± 0.4%</td>
</tr>
</tbody>
</table>

* % applies to temperature measured in °C
** -200°C to -170°C error is 0.8%
*** -200°C to -170°C error is 0.8%

Initial accuracy of a thermocouple is defined by the standards as either ‘Standard’ or ‘Special Limits of Error’. Expressed as ± degrees C or F or ± % of reading, whichever is greater.
ASME B40.200

- Consolidation and revision of four individual standards
  - B40.3, Bimetallic Actuated Thermometers
  - B40.4, Filled System Thermometers
  - B40.8, Liquid-in-Glass Thermometers
  - B40.9, Thermowells for Thermometers
- These individual standards provide terminology and definitions, dimensions, safety, construction and installation issues, test procedures and general recommendations.

Thermowells

RTDs and thermocouples are often protected with a thermowell. Strength and wake frequency factors need to be considered and there is a standard that defines safe configurations

- ASME PTC 19.3 TW-2010
  - Wake frequency and strength calculations
    - Uses length, diameter, material, fluid properties, and temperature to estimate a safe flow velocity
  - Immersion length - balance between sufficient length to avoid stem conduction and still stay within wake frequency and strength limits. Too long and it may break, too short and you will have an inaccurate measurement.

Measurement accuracy can be adversely affected by a thermowell unless a few precautions are taken. Wake frequency and strength calculations are probably the most important. These calculations will tell you how far the well can be immersed into your process based on the flow conditions (more on this later). This has to be balanced with the accuracy needs of the sensor to be immersed sufficiently to prevent stem conduction or immersion error.

Finally, time response is slower with the addition of a thermowell and for processes that change temperature rapidly this can be a significant error source.

The new release of the Thermowell Section of the Power Test Code incorporates the latest theory for wake frequency and strength calculations. If you’re a piping designer all this probably means a lot to you. For someone selecting a thermowell it may be a little like learning how to build a chainsaw to cut down a tree. Interesting but not really necessary. Your thermowell supplier will provide the calculations based on your process conditions and desired thermowell configuration. You need to specify that you want the calculations done to the 2010 version of the standard.
When a cylindrical object is placed in a flow there is a disturbance created on the downstream side that oscillates back and forth. The frequency of the oscillation increases as the flow rate increases. If the resonant frequency of the thermowell matches the frequency of the vortices the well will start to vibrate and will first damage the RTD and then the well will fail.

There are a lot of good illustrations of this phenomena on the internet. A search for Von Karman or wake frequency will return several.

This graph shows the acceptable flow rates for various thermowell designs and a ¼” diameter direct immersion RTD. Note that a short increase in immersion length has a large affect on the allowable flow rate.
This is typical of the information that is needed to perform the thermowell calculations.

A thermowell/RTD assembly was immersed in a bath to determine the stem conduction at various depths. At 4.5 inches most of the error has disappeared. As you can see the error is mostly independent of the bath temperature used. The error is expressed as a percentage of the delta T between ambient and process conditions.

An example of what can happen if the wake frequency and strength calculations are not done. This well incorporates a support part way down the stem to provide support but it wasn’t enough. A crack formed as outlined around the stem.

ASME PTC 19.3 does not recommend the use of supports such as this. Shorter immersion or larger diameters are the preferred solutions.
Connections to the process are accomplished with tapered pipe threads or adaptations of pipe or sanitary tubing flange connections. A blank or blind flange is modified to accept the thermowell stem and then easily attaches to standard flanges.

Weld-in styles are used for convenience or where exposed threads may collect contaminants such as in food processing or pharmaceutical production.

A specialty type of connection incorporates an O-ring to seal inside a sleeve welded to a tank. Sometimes referred to as an Ingold® fitting after the company that invented it for pH and oxygen sensors.
Questions? Comments?

Use the chat window to send us a question.

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