Temperature Measurement Accuracy with RTDs
Session II: Significance and Management of Errors

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What we’ll cover
Session 1: RTD Accuracy
- Terminology
- Error sources
  - Sensor
  - Installation
  - Instrumentation
  - Calibration

See the Presentation Notes at:
http://www.burnsengineering.com/rtdology/

What we’ll cover
Session 2
- Significance of errors
- Managing errors
  - Rules of thumb
  - Sensor selection
  - Installation recommendations
What we’ll cover

Session 3
- Calculating measurement system accuracy
  - Sensor selection
  - Performance
  - Calibration

Importance of Accuracy

Consistent product quality
Control energy costs
Efficient production
Third party validation

Error Sources

Sensor
- Interchangeability
- Insulation Resistance
- Stability
- Repeatability
- Thermal EMF
- Hysteresis
- Self Heating

Installation
- Time Response
- Stem Conduction
- Lead Wire
- RFI/EMI

Instrumentation
- Transmitter
- Controller/PLC

Calibration

An accurate and repeatable temperature measurement is important to maintain product quality and efficient use of energy dollars.

I divided the error sources into 4 categories. A possible fifth category would be errors associated with the characteristics of the process such as mechanical shock and vibration. Both of which can cause the sensor to drift or shift in resistance, typically seen as an increase in resistance.
Other Sources

Other sources can produce errors but are difficult to analyze without installation unique information.

- Vibration
- Mechanical Shock
- Thermal Shock
- Thermal Radiation
- Nuclear Radiation

These are a few other potential error sources. Application specific information is necessary to estimate the size of error.

Significance of Errors

Three error sources far outweigh all the others in significance. Stem conduction, time response, and interchangeability are the largest.

Sensor

- Interchangeability
- Insulation resistance

Installation

- Stem conduction
- Time response
- Lead wire

Calibration

Instrumentation

- Transmitter
- Controller
- Recorder
Interchangeability (largest component of sensor accuracy)

- Refers to the “closeness of agreement” in the resistance vs. temperature (R vs. T) relationship of a PRT to a pre-defined nominal R vs. T relationship.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Tolerance Nominal</th>
<th>Defining Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM E1137</td>
<td>Grade A</td>
<td>± [1 + 0.0017 T]</td>
</tr>
<tr>
<td>ASTM E1137</td>
<td>Grade B</td>
<td>± [1.25 + 0.00242 T]</td>
</tr>
<tr>
<td>IEC 60751</td>
<td>Class A</td>
<td>± [1.35 + 0.0002 T]</td>
</tr>
<tr>
<td>IEC 60751</td>
<td>Class B</td>
<td>± [1.3 + 0.0005 T]</td>
</tr>
</tbody>
</table>

Notes: 1. T is the value of temperature in °C; ±before symbol means 1-sided.

This graph shows the relationship between temperature and the interchangeability tolerance for each of the standards and classes. The ASTM Grade A has the tightest tolerance.

RTDs are manufactured to be 100 ohms at 0°C. The two standards provide a common target for them to hit and the acceptable tolerances. As the temperature diverges from 0°C the tolerances increase.

System calibrations are a good method to reduce interchangeability error. Placing the sensor in a known temperature bath while it is connected to the control device allows the output to be adjusted at the control device to match the bath temperature. About 85% of the interchangeability can be eliminated this way.

A second method to eliminate 85% of the interchangeability error in a measurement system is to use a PRT in conjunction with a transmitter that has matching capability. Transmitters with matching capability allow a specific R vs. T relationship to be entered into the transmitter software. In the case of an analog transmitter, the potentiometers for zero and span are adjusted to match the...
unique PRT resistance at the end points of the range. This method will nearly eliminate the interchangeability error. However, errors due to calibration and some external influence effects will still be present.

When the matched calibration option is specified there is no need to select a PRT with a tight interchangeability because the actual R vs. T relationship, which is determined by a comparison calibration, is used to calibrate the transmitter. A less expensive Grade B sensor can be specified. The table below shows the improvement in accuracy that can be achieved using this method.

<table>
<thead>
<tr>
<th>Temperature Measurement Accuracy with RTDs</th>
<th>© Burns Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matched transmitter example:</td>
<td></td>
</tr>
<tr>
<td>- PRT in a process at 121°C using a transmitter with .1°C accuracy.</td>
<td></td>
</tr>
<tr>
<td>Grade B</td>
<td>Grade A</td>
</tr>
<tr>
<td>PRT Tolerance at 121°C</td>
<td>±.76°C</td>
</tr>
<tr>
<td>Transmitter Accuracy</td>
<td>±.1°C</td>
</tr>
<tr>
<td>Combined System (RSS)</td>
<td>±.77°C</td>
</tr>
</tbody>
</table>

As you can see, matching is a very economical method to improve your system accuracy.
Resistance information is available from a calibration certificate for the sensor to be matched. Some transmitters will accept the temperature coefficients generated from a full calibration and provide the best accuracy match.
Insulation resistance

- Electrical resistance between the sensing circuit and the metallic sheath of a PRT

An important electrical check that should be performed as part of any calibration. The test is performed with 50 or 100 VDC applied between the leads and sheath.

Some manufacturers use 500 VDC and 500 or 1000 megohms as a minimum at room temperature.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Temp (°C)</th>
<th>Min. IR (MΩ)</th>
<th>(100 ohm PRT(°C))</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM E1137</td>
<td>25</td>
<td>100</td>
<td>.0003</td>
</tr>
<tr>
<td>ASTM E1137</td>
<td>300</td>
<td>10</td>
<td>.0130</td>
</tr>
<tr>
<td>ASTM E1137</td>
<td>650</td>
<td>2</td>
<td>.1700</td>
</tr>
<tr>
<td>IEC 60751</td>
<td>25</td>
<td>100</td>
<td>.0003</td>
</tr>
<tr>
<td>IEC 60751</td>
<td>100 to 300</td>
<td>10</td>
<td>.0130</td>
</tr>
<tr>
<td>IEC 60751</td>
<td>301 to 500</td>
<td>2</td>
<td>.1200</td>
</tr>
<tr>
<td>IEC 60751</td>
<td>501 to 850</td>
<td>.5</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

IR decreases with an increase in temperature and that’s why manufacturing specifications are set high at room temperature where the test is performed.

Low IR can cause a significant error. Laboratory standards may have IR of 1000 megohms or may be measured in the terraohm range. Higher is better.

Several sources can cause low IR. Most common is moisture leaking into the sensor. It may be trapped during manufacture and cause variations in IR as the moisture moves around inside the probe. Sometimes the sensor may be dried out by placing it in an oven and heating for several hours. The sensor should be checked frequently to insure that moisture did not leak back in.
Ways to minimize

- PRT is designed properly for the application
  - Moisture seal can handle thermal/mechanical environment

- Early detection of problems
  - Measure IR often
  - >200 megohms at 20°C

Most important is to make sure the sensor is designed to meet the rigors of the application. One of the most difficult applications is monitoring temperature inside a steam autoclave. When the chamber is evacuated, any air inside the sensor can leak out, and then when steam is introduced it goes right inside the sensor and you have low IR. A properly sealed sensor will prevent this “breathing” and insure a long and accurate life.

The external parts of the sensor act like a radiator having a chilling effect on the sensing element. Pathways are from the metal sheath, internal leadwires, and even the potting material.
To minimize
- Choose the right sensor
- Use a sensor / thermowell that has sufficient immersion into the process 10 x sheath diameter plus sensitive length
  - 3.5" for .25 sheath and 1" sensitive length
  - 1.5" for .125 sheath.
- Insulate the exterior portion to isolate it from ambient conditions
- Use special tip sensitive designs
- Consult manufacturer for appropriate sensor

The immersion length rule works well for direct immersion style sensors.

Thermowell assemblies act a little differently as will be seen in the upcoming graph.

Sensor design also has a large influence on stem conduction. Smaller diameters, low mass, non-heat conductive materials will help to minimize stem conduction.

Difficult to analyze, can be very sensitive to depth.
- Heat transfer conditions heavily influence the rule.
- Error directly proportional to $\Delta T$

Because there are so many variables an actual error value can be difficult to determine. Process fluid characteristics, flow rate and ambient conditions are just a few of the variables.

There are many styles of surface mount sensors and each has a preferred mounting method. Whether bolted, strapped, or glued on, the accuracy of each suffers from the effects of the ambient conditions and mounting location. Each requires external insulation to isolate it from ambient conditions. The immersion styles are less affected by stem conduction.
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.

Installation into a tee with the sensor parallel to the flow can allow for longer immersion length and minimal stem conduction. The sensor on the right is the preferred installation method.

A special elbow fitting with an integral thermowell allows for sufficient immersion length in tubes down to 0.5" diameter.
In tubes smaller than 1” the tube is flared to allow for the thermowell without constricting flow through the elbow.

A non-intrusive is a hybrid surface mount sensor where the insulation and mechanical protection is built-in. This design still shows some conduction error because insulation is not 100% efficient and with a surface mount the pipe temperature is being measured and not the actual fluid.

This style sensor is useful for small tubes or where the product is viscous or sticky and would build up on an immersion sensor.
**Time Response**

- Getting the sensor to follow as close to the process as possible
- Time constant – time required for the sensor to respond to 63.2% of a step change in temperature while in water moving at 3 fps

The time response provides a standard method for comparing the relative "quickness" of each style sensor. The test starts with the sensor in 0°C water and then placed in room temperature water moving at 3 fps.

- The less thermal resistance between the sensor and the process, the better
- Smaller diameter probes
- Direct Immersion or special fast tip thermowell

The fast response tip thermowell has a time constant of 4 seconds which equals that of a 0.25" diameter direct immersion sensor.

This graph compares the time response of several styles of sensors. The fastest is the direct immersion style and the surface mount the slowest.
Addition of heat transfer compound (HTC) can improve the time response of thermowell/RTD assemblies.

Lead wires used to connect the sensor to a process control instrument can cause a measurement error. Two and three wire circuits have the largest errors and the 4 wire will nearly eliminate the error.
Two wire circuits simply add the lead resistance to the sensing element resulting in very large errors.

A three wire circuit will add no error if each of the three legs have the same resistance. Unfortunately in the real world there is a difference and that causes an error.

The current potential method or 4 wire circuit is the most accurate and has little or no error associated with it.
Significance of Errors

Sensor
- Interchangeability
- Insulation resistance

Installation
- Stem conduction
- Time response
- Lead wire

Calibration

Instrumentation
- Transmitter
- Controller
- Recorder

Calibration Errors

Every sensor has a resistance check performed to determine if it is within tolerance. That process has an error associated with it that needs to be added to the sensor error.

Calibration Errors

These are the sources of error associated with the calibration. Each is very small but still needs to be taken into consideration.
To minimize:
- Obtain a high quality/accuracy calibration for the sensor
- Calibrate sensors at the correct intervals

Calibration Errors

Significance of Errors

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Instrument specifications need to be reviewed carefully to be sure you have all the error sources identified for your application. Ambient temperature can affect the accuracy.
Many sources contribute to the total error, some are PRT driven, some are application driven.

ASTM E1137 and IEC 60751 standards provide some performance information, but it is not comprehensive or particularly stringent.

Knowing PRT accuracy is not enough.

Specific details must be known about the application for an accuracy estimate to be made.

Understand the sources of error and focus on the most significant

Identify the uncertainty that is present

Reduce factors that contribute to the error

- Installation
- Sensor selection
- Calibration
- Instrumentation
- Environment

Determine what the acceptable level of error is for your application and select materials based on those decisions.

I think the most important thing to take away from this session is the need to match the sensor design to your process and installation detail. The larger errors are usually caused by the installation or using a sensor not designed for the application.

Use the chat window to send us a question now

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952-567-6413

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- Measuring Temperature in Small Diameter Lines

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