Surface vs. Immersion Temperature Measurements

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Today’s Discussion

Selecting an RTD or thermocouple
- Placement
  - Surface mount
  - Immersion
- Protection
  - Hazardous atmosphere
  - Ambient temperature
  - Water
  - Corrosive/erosive
  - Sunlight
- Performance
  - Accuracy
  - Durability
  - Long term stability
- Price
- Service life

There are five main areas to look at when selecting an RTD for a particular application. We'll go through each of them and add features to address each area.

For a pipe there are two options, surface mounted or immersion. The two parts on the left are just two of a wide variety of surface mount sensors available and the two on the right are examples of the two most common styles of immersion sensors.
Installation of a surface mount sensor can be accomplished with a hose clamp, tape, or adhesive.
A third category of sensor style is a flush mount. The sensor replaces part of the tank or pipe wall to achieve a more intimate contact between the sensing element and the process fluid. Features are faster time response and less conduction error.

The non-intrusive style sensor incorporates an insulated enclosure to shield the surface mounted sensing element from ambient conditions. The assembly is completely waterproof and can be fitted with cable or a connection head.

Magnified view of a thin film sensing element shows the platinum film trace and the protective blue glass layer. Very small, low mass makes an excellent sensing element for surface measurements.
Installation Tips

Accuracy is highly dependent on the installation method and conditions to which the sensor will be exposed. Here are a few installation tips to help insure accuracy:

- Use a thermally conductive paste to reduce the measurement error by up to 50%. Also helps to minimize conduction errors.
- Insulating over the sensor after it is installed will prevent heat loss around the sensor and help isolate the sensor from the ambient conditions. Test data shows that the presence of insulation over the surface sensor can reduce the measurement error by up to 70%.
- Combining both the conductive paste at the interface and insulation over the top of the sensor can reduce the measurement error by up to 90%.
- Some designs need protection from liquid water.
- Select a location where there is no sunlight, other heat radiation, and minimal air movement. All can affect the measurement accuracy.

Based on test data using 50°C water flowing through a 0.5 inch SST tube at 3 feet per second. Ambient conditions varied between still air and forced airflow over the installation location.

Placement

Surface mount - positives

- Easy installation
- No flow obstruction
- Low cost

Surface mount - negatives

- Requires insulation for best accuracy
- Minimal protection from ambient conditions
- Difficult to calibrate
- Measures pipe surface

Installation method can have a large effect on the measurement accuracy. Use of thermally conductive paste, epoxy, silicone rubber or similar material will help speed up the response time and minimize conduction errors.
Some typical surface mount applications

- Bearing temperature
- Small diameter lines
- Tube skin in heat exchangers
- Small aircraft engine temperature
- Exhaust temperature
- Corrosive or erosive fluids
- Viscous or sticky fluids

An immersion sensor overcomes the negatives of the surface mount and in most cases dramatically improves the measurement accuracy. Introducing a sensor into the process does add some additional factors to consider, the most important being immersion length.

Direct immersion of a small diameter sensor gives an accurate measurement at low cost. It is not always possible or desirable though because of maintenance or durability considerations.
Of all the error sources, stem conduction seems to cause the most problems especially in tight locations. A thermowell and RTD assembly requires at least 4.5” of immersion to minimize the error. A direct immersion RTD requires at least 10x the probe diameter plus the sensitive length. Most RTDs have a sensitive length of 1”. So for a ¼” diameter RTD, the minimum immersion is 3.5”.

Insufficient immersion will allow the ambient conditions to have either a heating or cooling effect on the sensing element. Error magnitude increases as the difference in the ambient temperature and the process temperature increase.

Surface mount sensors are heavily influenced by the ambient conditions. An insulating covering is required to get the best accuracy.
A thermowell and 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. Our example has a 2.5” immersion so estimating from the graph gives us an error of about 0.45°C which is our second largest error source behind interchangeability.

To gain additional immersion depth a tee fitting makes an excellent choice. Flow should be directly at the tip of the sensor to minimize vibration and drag effects.

Adding a thermowell provides protection for the sensor and reduces maintenance. Flow induced vibration is resolved with a thermowell in our sample application.
This graph shows that our ¼” diameter direct immersion sensor will vibrate due to the 100 fps flow rate. Adding the ¾” NPT thermowell allows a comfortable margin of safety with well over 250 fps capability for the 2.5” immersion length selected.

We’ve protected the internal part of the sensor and now we need to look at the outside.

A connection head is the best method and provides a convenient place to attach lead wires or to house a local transmitter.
Numerous styles and materials, from plastic to aluminum, are available. Some carry ratings for use in hazardous atmospheres.

Heads provide protection for transmitters and local indicators.

Hazardous atmospheres require an RTD and connection head assembly that carry an appropriate rating.
Hazardous atmospheres require an RTD and connection head assembly that carry an appropriate rating. Not many surface mount RTDs are rated for hazardous atmospheres. Fortunately ¼” diameter or smaller RTD or thermocouple that carries a hazardous area rating can be used as a surface mount sensor. A couple of hose clamps and insulation are all that is required for installation.

A connection head is attached to the thermowell and sensor typically with a pipe nipple. The most versatile is the union connection.

In addition to making sensor removal easier, the union allows the conduit port to be rotated to line up with the facility wiring.

Approximately 3” is a good minimum length for an extension. This insures that the temperature in the head does not overheat from the process. Transmitters and the moisture seal on the sensor can be adversely affected by temperatures over 85°C.
Error Budget

- Sensor accuracy
  - Interchangeability
  - Matching to transmitter
  - Thin film or wire wound
  - Repeatable and stable

- Measurement accuracy
  - Installation
  - Time response
  - Control system
  - Repeatable if ambient conditions are constant

- Immersion sensors are more accurate than surface mount

Accuracy of the sensor and accuracy of the measurement are most times quite different.

Sensor accuracy is determined mostly by the manufacturing interchangeability and the style of sensing element. The wire wound style has the widest temperature range and lowest drift.

Measurement accuracy includes the sensor accuracy and the installation effects. In addition, time response can be a large factor in the measurement accuracy.

Stability or long term drift is an important consideration in selecting an RTD for best accuracy. As you can see from the graph, as temperature goes up the drift becomes much more significant. This graph shows some worst case drift estimates for RTDs. Thermocouples may drift faster depending on the conditions it is exposed to.

High accuracy insures product quality and efficient use of your energy dollar.
This graph shows the relative time response difference of the various types of sensors and installation methods. The direct immersion has the fastest response and the slowest is an RTD and thermowell assembly with a sloppy fit of the RTD into the well.

Time response can be a large error if the RTD does not keep up to a rapidly changing process temperature.

Adding a transmitter can improve accuracy when a long run of lead wire is required. They also provide a more robust signal that is less susceptible to interference from electromagnetic or radio frequency interference.
The goal is to minimize the total life cycle cost of the measurement point while maximizing performance. Numerous costs need to be considered from the sensor cost to the cost of carrying a spare in inventory.

There are many RTDs that have been in service for 20+ years and are still performing within original specifications. To achieve this kind of lifetime and the lowest life cycle cost, careful consideration needs to be given to all the selection factors.

Summary

Surface mount
- Low cost
- Easy installation
- Protection required for ambient conditions

Immersion
- Best accuracy
- Consider wake frequency and strength when selecting
- Requires sufficient immersion to overcome stem conduction