Temperature Measurement

This article is about some common types of temperature sensors, limitations of some of the sensors and Internet sources of temperature measurement information. Most manufacturers of temperature sensors will provide technical information and papers about this subject.

Temperature can be measured by a diverse array of sensors. All of them infer temperature by sensing some change in a physical characteristic. The most popular types are: thermocouples, resistive temperature detectors (RTD's), thermistors, infrared detectors, bimetalic devices, liquid expansion devices and change of state devices. This article will focus on the two most popular types, thermocouples and RTD's.

Thermocouples

Thermocouples consist of two electrical conductors made of different metals that are joined at one end. Changes in temperature at the measurement junction induce a change in electromotive force (emf) between the other ends. Refer to the International Temperature Scale of 1990 (ITS-90) for standardized tables of temperature vs thermocouple emf valves. ISA and ASTM have designated letters for particular types of thermocouples. There are two groups, the base metal thermocouples J, K, T, E and N and the precious metal thermocouples R, S and B. Each type has a characteristic emf vs temperature curve and application range. The EMF curve is very dependant on the composition of each conductor. Type J and K are the most widley used in industrial applications. Type J (iron vs copper-nickel(Constantan)) is versatile in that it can be used in both oxidizing and reducing atmospheres up to 1,400°F. Iron rusts at low temperatures where condensation can form. Type K (nickel-chromium(Chromel) vs nickel-aluminum(Alumel)) can be used up to 2,300°F in an oxidizing or inert atmosphere.

Type K thermocouples exhibit a number of instabilities and inaccuracies, particularly at higher temperatures, changing their emf/temperature characteristics. In reducing atmospheres (lack of oxygen) at temperatures of 1,500 to 1,750°F the positive thermoelement forms a greenish chromic oxide, commonly known as "green rot". This causes a decrease in the electromotive force of the thermocouple. Type K is also subject to aging when exposed to 800 to 1,200°F for a few hours. Temperature cycling above 1,400°F and then below 700°F causes a random error due to changes in the composition (inter-granular structure) of the conductors.

Solutions to the problems of Type K thermocouples include using metal sheathed mineral insulated thermocouples, Stabilized (pre-aged) Type K conductors or Low-Drift (annealed above the operating temperature) Type K conductors depending on the application. Other types of thermocouples, which do not drift such as Type N, could be used in place of Type K to avoid these problems. Quite often the Thermocouple cabling from sensor to control room or multiplexor box is already Type K and would be costly to change to another type of conductor.

Type N (nickel-chromium-silicon(Nicrosil) vs nickel-silicon(Nisil)) thermocouples exhibit a much greater resistance to oxidation-related drift at high temperatures. In 1986 it was thought that Type N would make Type E, J, K and T obsolete. Type N became popular in Europe and Austrailia but has not become as populat in North America yet.

Resistive Temperature Detectors (RTD's)

RTD's contain a sensing element whose resistance changes with temperature. The sensors are usually packaged so they can be placed into a position in the process where it can reach the same temperature. Platinum wire or film RTD's are the most common type in use today. Platinum RTD's are used to measure temperatures from -450 °F to 1200 °F.

Sensor selection requires answers to a number of questions:

- What is the temperature range to be measured?
- What accuracy of measurement is required?
- What environmental conditions may cause the sensor not to perform?
- What method of signal transmission is to be used?

Temperature Range

Platinum RTD's are capable of measuring from -450 °F to 1200 °F. Thermocouple ranges are 32 to 1400 °F for Type J, -328 to 2,300 °F for Type K, -328 to 660 °F for Type T, 32 to 2300 °F for Type N, 32 to 2640 °F for Type R and 1472 to 3092 °F for Type B. Check the accuracy of the thermocouple over the measured range. For example the accuracy of a Type K thermocouple is 2% of reading from –328 to –166°F, 4°F from –166 to 559°F and ¾% from 559 to 2282°F. Look at the sensor signal change over the measured temperature range to see the different sensitivities and non-linearities.

Measurement Accuracy

RTD’s are manufactured to DIN standards which have different grades of accuracy which are only specified at 32°F. A 100 ohm RTD which meets Grade A accuracy would be 100 +/- 0.12 ohms (+/- 0.12%) at 32°F and Grade B would be +/- 0.06%. Higher resolution Platinum RTD’s are available which have a resistance of 500 ohms at 32°F.

Thermocouple accuracy is defined as limits of error over a temperature range. The range is specific to the type of thermocouple and has two or more temperature bands each with a specific limit of error. There is more than one accuracy classification for thermocouples. Standard limits of error define the normal accuracy specification. Special limits of error define an accuracy specification of half the normal specification. Manufacturers catalogs and standards contain technical information about each type of thermocouple, including emf/temperature tables and temperature ranges vs limits of error.

Sensors mounted in thermowells should be spring loaded to press the sensor tip to the bottom of the thermowell for good contact. Oil or grease can be inserted into thermowells for improved contact as long as the operating temperature does not exceed the flash point of the oil or grease.

Environmental Conditions

Environmental conditions can affect the life and performance of temperature sensors. Thermocouples and RTD’s can be supplied with mineral insulation and metal sheath to insulate the conductors and protect them fron the environment. The insulation and metal sheath must be rated above the highest operating temperatures. Magnesium oxide is a common insulation material which is suitable for –320°F to 1,250°F. Common sheath metals include 300 series stainless steel, Inconel, Incoloy and Hastelloy.

The air atmosphere can cause corrosion to the thermocouple wires in the thermocouple head and thermowell if the sensors are not sheathed and sealed. Water can cause Type J iron conductors to rust.

RTD sensors tend to be more fragile than thermocouples. Temperature expansion due to rapid temperature changes and vibration can damage the sensor and wiring. RTD sensors are usually fabricated as wound wire on a core or helical coils in a tube with mineral insulation packing to reduce vibration effects.

Signal Transmission

The signal transmission system can have a negative effect on the accuracy and reliability of the temperature signal. This is true for thermocouples and RTD’s. Thermocouple signals must be transmitted via thermocouple extension wire made from the same material as the thermocouple elements. Use of wire materials other than the thermocouple materials will result in errors where the ambient temperature changes. Voltage drops could also develop which would cause additional errors.

RTD extension wire can cause an error because the resistance of the wire is added to the sensor resistance. 3 and 4 wire RTD’s have compensating leads that can be used to eliminate the wire resistance.

International Standards

IEC-60584	Thermocouples (3 parts)
IEC 751:	Industrial Platinum Resistance Thermometer Sensors.
ANSI-MC96.1	Temperature Measurement Thermocouples.
ASTM E1137-87	Standard Specifications for Industrial Platinum Resistance Thermometers.

References

1) Leewis, Wes. "International Standards for Specifying Temperature Sensors", ISA Edmonton Section, 1990.
2) ASTM STP 470B, Manual on the use of Thermocouples in Temperature Measurement.
3) Wang, T.P. "Thermocouples for High Temperature Applications", ISA Advances in Instrumentation, Volume 42, 1987.
4) Wang, T.P. and Martincavage, J.R. "The Role of Temperature Sensors and High tech Instrumentation on the Bottom Line of the Chemical and Petrochemical Industries", ISA Instrumentation in the Chemical and Petrochemical Industries, 1987.
5) "Thermocouple Selection and Maintenance" Intech April 1991.
6) Guide to Thermocouple and Resistance Thermometry by TC Ltd. Uxbridge England.

Internet Technical Information

"How to Select and Use the Right Temperature Sensor" (www.pyromation.com/pdf/default.htm)
Determine which sensor to use, RTD or Thermocouples.
"Temperature Sensors" (www.sensycon.de/txt/txt_21_e.htm) Plainum resistance elements - Introduction, General Assembly, Slot type, Thin film type and low temperature measurements.
Minco Reference Library (www.minco.com/reflib.htm)
Omega Technical Reference (www2.omega.com/reference.html)
Watlow Reference Data (www.watlow.com/ref/index.htm)

Manufacturers Web sites

Search the ISA Directory of Instrumentation at www.isa.org/directory for temperature sensor manufacturers.

Acrolab	www.acrolab.com
Minco Products	www.minco.com
Omega Engineering	www.omega.com
Pyromation	www.pyromation.com
Rosemount	www.rosemount.com/products/temp.htm
Sensycon	www.sensycon.de
TC Ltd.	www.tc.co.uk
Thermo-Kinetics	www.thermo-kinetics.com
Watlow	www.watlow.com
Weed Instrument	www.weedinstrument.com

Standards Organizations

ANSI	www.ansi.org
ASTM	www.normas.com/
IEC	www.iec.ch/
ISA	www.isa.org

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www.xcelco.on.ca/~btsmith/temper.htm

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