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Course № IC-2001

Fundamentals of Temperature Measurement

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Fundamentals of Temperature Measurement

This course covers the basic methods used to measure temperature in commercial, municipal and industrial applications. It is intended to be an introductory course and somewhat broad in discussing early-to-current methods of measurement. It will also discuss applications and conditions that can influence the accuracy and repeatability of various types of electronic temperature sensors; including thermocouples, thermistors, RTDs, and infrared technology.

Brief History of Temperature Measurement

In the early 1600s an Italian physicist named Santorio Santorio developed a crude thermometer-like device which he referred to as a “thermoscope”. In some ways resembling the liquid-filled thermometer of today, it lacked any sort of calibrated scale; and the tube was open to the atmosphere, which adversely affected its accuracy due to variations in barometric pressure.

Also in the early 1600s, among his other scientific credits, Galileo Galilei reportedly invented another style of thermoscope, sometimes referred to as a “Galileo Thermometer”. This type of instrument, which is still available as more of a decorative item than a functioning thermoscope, operates on the principal of buoyancy. As the temperature of the clear fluid contained within its vertical glass cylinder increases, the fluid expands and its density decreases, causing small glass spheres that are each filled with a uniquely-colored fluid that has a slightly different specific density corresponding to a specific temperature, to sink within the cylinder as their density becomes greater than that of the clear fluid in which they are submerged. The temperature is read from a small engraved metal disc on each sphere. The current approximate temperature is indicated by the lowest floating glass sphere within the cylinder, such as the yellow liquid filled glass sphere appearing in the thermoscope shown in Figure No. 1 below.

Further development of temperature measurement, still using a fluid as the indicator and a calibrated scale to measure the fluids displacement in relation to temperature is credited to such scientists as Ole Christensen Røemer, who in 1701 reportedly made one of the first practical thermometers using red wine as the indicator; Daniel Gabriel Fahrenheit, who soon after developed a more accurate mercury-filled thermometer and thermometer scale; and Anders Celsius (also in the 1700s), who developed a metric scale of temperature measure.   William Thompson (Lord Kelvin) and William Rankin were credited in the mid-1800s with having broadened the calibrated temperature measurement scale range to include “absolute zero”, thus making it more useful for research purposes.

As technology in the areas of physics, metallurgy and electronics have progressed since the 1800s, so has temperature measurement technology and measurement instrumentation in general.

Figure No. 1 – Galileo Thermometer (Image Source: Wikipedia)

Liquid filled temperature indicators were followed by the development of bimetallic and gas-filled instruments, which were later followed by electric and more recently solid state electronic devices. Please note that I said “followed by” and not “replaced by” the next generation of instrumentation. Virtually all of the mentioned technologies are still in use and still commercially available; and that is because each has inherent qualities that make it more suitable than another type for a particular application. For that reason there are many hundreds of variations of the various types and styles of temperature measurement instruments.

Measurement Scales

There are several commonly used scales of temperature measurement that were created in the 16th and 17th centuries that are still in use today. They include Fahrenheit, Centigrade (also referred to as Celsius), Kelvin, and Rankin. Each is based on a different scale, and must be mathematically converted from one to another in order to determine the equivalent value in another scale. For the most part, outside of scientific applications, the United States uses the Fahrenheit scale, while most of Europe and other parts of the world have standardized on the centigrade scale. The Fahrenheit scale uses 32 degrees as the freezing point of water and 212 degrees as the boiling point of water. By comparison, the centigrade scale uses zero as the freezing point of water and 100 degrees as the boiling point of water. Therefore, in order to convert a temperature from Fahrenheit to centigrade, one would have to use the equation

$$\text{Degrees C} = (\text{Degrees F}-32) \text{ x } 5/9$$

The centigrade scale conforms to the metric system, which is based upon units of ten.

Kelvin and Rankin scales are primarily used in scientific research and reporting, where temperature conditions outside of the normal day to day environment are investigated and explored. It is not necessary that we know each day how close the outdoor or indoor temperature, for example, are to absolute zero. Absolute zero is considered to be minus 273.15 centigrade, or zero degrees Kelvin - the theoretical temperature at which molecular movement, which is the fundamental source of heat energy, ceases. In other words, there is a total absence of heat at absolute zero. On a Kelvin scale the freezing point of water is 273.15 and the boiling point of water is 373.15 degrees.

Converting a temperature from Fahrenheit to the Kelvin or to Rankin equivalent requires using the formulas

$$\textit{Degrees K} = (\textit{Degrees F} + 459.67) \times 5/9$$

$$\textit{Degrees R} = \textit{Degrees F} + 460$$

We will not go further in depth in our discussion of the various temperature scales, as they are easily converted from one to another and the rest of this course topic will use either Fahrenheit or centigrade as the reference scale.

Early Methodology

As already mentioned, the earliest methods of temperature measurement were mechanical in nature and used a fluid, such as colored water, oils or alcohol, as the indicator; and then applied a linear scale of change in the fluid’s density in relation to its temperature. For centuries, what became a standard of temperature measurement was the glass tube filled with liquid mercury and later largely replaced by one containing red alcohol, as shown in Figure 2 below.

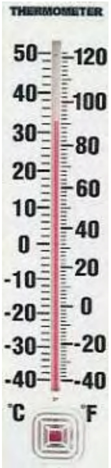

Figure No. 2 – Standard Glass Thermometer

Another, non-fluid method of measuring temperature that was developed much later uses a helically-wound bimetallic strip to operate a dial type indicator, such as that shown in Figure No. 3. A bimetallic strip consists of two thin layers of different metals that have different coefficients of expansion, such as brass and steel that have been bonded together. With a given change in temperature, the two bonded metals expand at different rates, causing the strip to distort (bow) in the direction of the metal with the lesser coefficient of expansion. By arranging the bimetallic strip in a helical pattern, the differences in the expansion rates of the bonded metals cause the helix to partially coil or uncoil as their temperature changes. That movement, when mechanically attached to the dial of an indicator, causes the dial to move somewhat proportionally in response to a change in sensed temperature.

Figure No. 3 – Dial Thermometer

Older style, non-digital, wall-mounted room thermostats that control central residential and commercial heating and air conditioning systems have an integral thermometer mounted in the thermostat cover. By carefully removing the cover and examining the back of it, you can typically see the helical bimetallic element of the thermometer. U.S. patents are held on the helical bimetallic strip designs that are currently on the market.

Yet another mechanically-actuated type of temperature measurement device used the principal of the expansion of gases (vapor) according to the ideal gas law. This type of device is often referred to as a “filled system” thermometer. As temperature increases (and vice-versa) the liquid or vapor will expand and increase the pressure within a metallic bulb (hollow probe) and attached capillary tube to move a connected diaphragm or bellows at the indicator on the other end of the capillary. Movement of that diaphragm or bellows is then mechanically converted into a calibrated dial movement using a cantilever system. An example of a remote bulb thermometer is shown in Figure No. 4.

Figure No. 4 – Remote Bulb Thermometer

The advent of the remote bulb thermometer made it possible to monitor temperature without being very close to the point of measurement. When the accessibility of the measurement location is difficult under normal circumstances, such as reading the temperature of water flowing through a pipe that is fifty feet in the air, having a remote bulb that allows the indicator dial to be down at eye level is very desirable. An added advantage of this type of expanding fluid device is that it operates without electrical current. Therefore, it cannot produce an electrical spark during normal operation, making it intrinsically safe for use in hazardous areas where a flammable or explosive vapor may be present and ignited by the occurrence of a spark.

Development of light emitting diodes (LEDs), liquid crystal displays (LCDs), and large scale integration of electronics to a size and cost that are attractive has driven changes in the technology of temperature measurement, as it has many other things, in recent years.

Although still popular and somewhat cost-effective, small portable thermometers such as the one appearing on the left in Figure No. 5 are being gradually replaced with a digital version resembling that of the digital pocket thermometer appearing on the right in Figure No. 5.

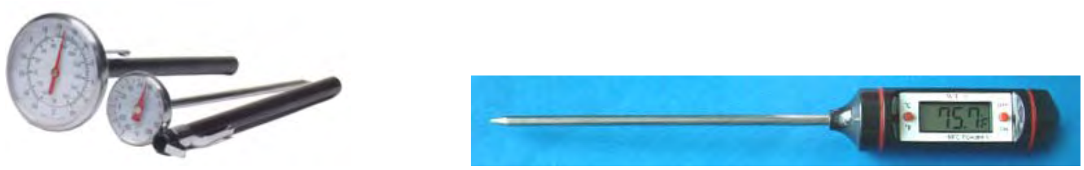

Figure No. 5 – Dial and Digital Pocket Thermometers

Digital thermometers have the advantage of being more easily read and to a more precise value, while dial thermometers have the advantage of not requiring a battery.

As mentioned previously, each device has its own qualities that make it better suited for a particular application. When determining what type of temperature measurement device is most suitable for your specific application, consider accuracy, repeatability, reliability, durability, suitability and cost. In terms of suitability, the environment in which it will be used is a very important consideration. Other things, such as the degree of accuracy and reliability needed, will tend to drive the average cost of the device.

Electronic Temperature Sensors

Many applications that require remote monitoring and/or remote control of temperature rely on a solid state device for electric and or electronic control, such as a thermocouple, thermistor, or a resistance temperature detector (RTD). So what are these devices, how do they differ from one another, and when and where do you use one type rather than another?

Thermocouples

Let's start with the one that has been around the longest, and has historically seen the most use – the thermocouple. A thermocouple is a device that consists simply of a bonded juncture of two dissimilar metal wires that produces a very small amount of dielectric current that varies with the temperature to which the primary junction, sometimes referred to as the "bead" is exposed. This phenomenon is referred to as the "Seebeck Effect", which was named after Thomas Johann Seebeck, a physicist who is credited with its discovery in 1821.

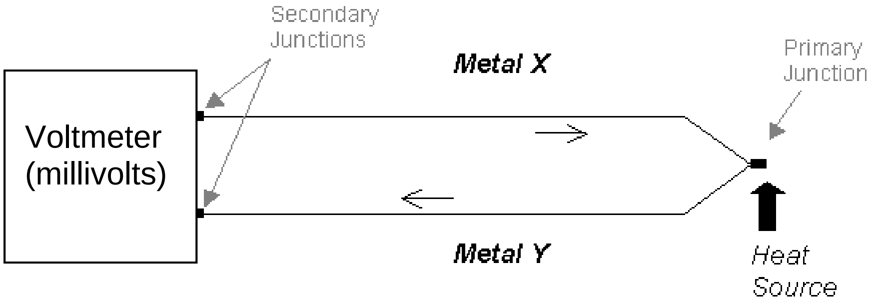

Figure No. 6 – Thermocouple Diagram

Thermocouples used for temperature measurement have certain advantages and disadvantages when compared to other types of electronic temperature measurement. A clear advantage is that a thermocouple produces its own electrical signal, albeit in the millivolts (1/1000th of a volt) range. Most modern thermocouple-style temperature measurement systems use an electrical transducer to convert the millivolts signal range into an industry standard, calibrated range of 0-10 volts dc or 4-20mAdc (milliamperes), making them compatible with a wide array of monitoring, display, and recording instruments.

The electrical symbol typically used to represent a thermocouple junction on an electrical schematic is shown in Figure No. 7 below.

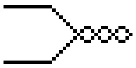

Figure No. 7 – Thermocouple Electrical Symbol

Another advantage of thermocouple is the ability to use them to measure relatively high and relatively low temperatures. Therefore, they are commonly used in industrial and combustion applications.

A disadvantage of these devices is that, in order to function properly, the same dissimilar metals used at the junction must be used for the signal wiring all of the way back to the indicator or recorder as shown in Figure No. 6. Any termination devices, such as terminal blocks, must also have the same dissimilar metals at each junction. If dissimilar metals were used as splices or conductors, we would be creating another junction of dissimilar metals which would act as another thermocouple. Thermocouple wire tends to be more expensive than standard signal wiring consisting of stranded copper conductors that is used for the other types of temperature sensors we will discuss. It also must be ordered from suppliers that stock such wire, which is less common than standard copper wire.

The thermocouple wire considered to be industry standard are given letter descriptions, such as the J or K-type. Each uses different dissimilar metals and has different temperature ranges over which they are accurate, as illustrated in Chart No. 1.

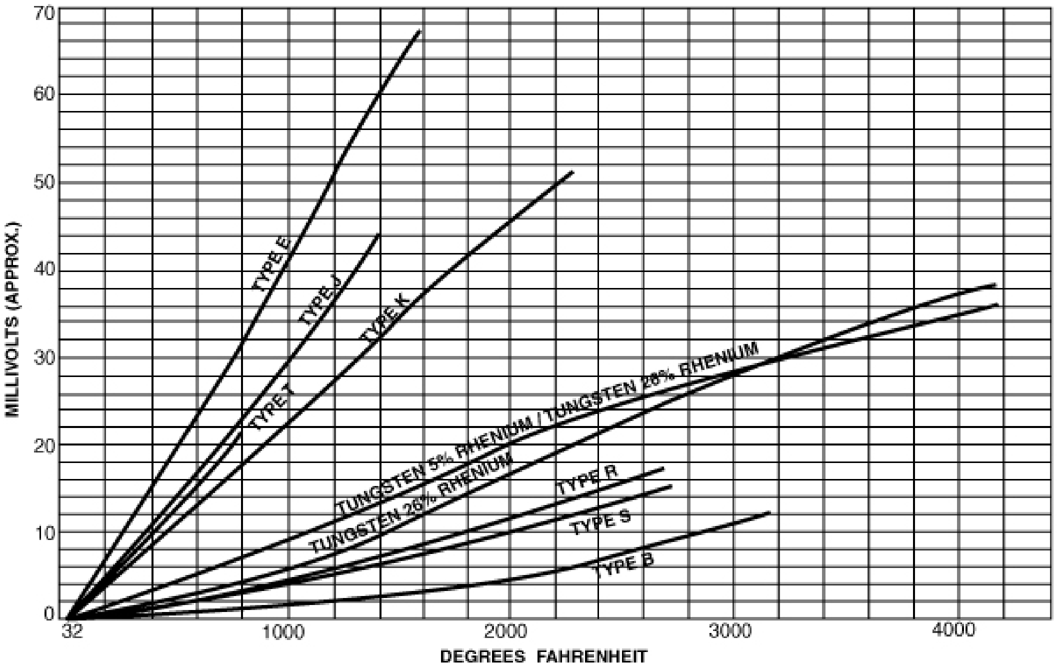

Chart No. 1 – Various Thermocouple Types w/ Their Output and Range

Type J and K thermocouples are the most common types that are readily available and in use today. Type J thermocouples utilize iron and constantan wire; and Type K thermocouples utilize chromel and alumel wire and can be used in higher temperature applications than Type J thermocouples, as can be seen on Chart No.1.

Another potential disadvantage of thermocouples as compared to some other types of temperature sensors is the broad range of the sensors, which tends to give them a poorer resolution. It is difficult to accurately measure temperature down to tenths of a degree Fahrenheit (F) when the device has a range of several thousand degrees and the output signal range is already being measured in millivolts. Typical accuracy of a thermocouple that has a range of -200 to 2,000 degrees Centigrade (C) is approximately 1 degree C (1.8 degrees F).

Thermistors

Thermistors are a type of resistor that varies their resistance in inverse proportion to a change in their temperature. In other words a thermistor's resistance decreases as its temperature increases. According to historians the thermistor was invented by Samuel Rubin in 1830.

Modern thermistors are typically made from either a ceramic disc or a cast chip of a semiconductor material such as metal oxide, although they are also available with stainless steel jackets to protect them from harsh environments. They function under the principal that raising the temperature of a semiconductor device increases the number of electrons that are able to move about and carry a charge.

An encapsulated thermistor, such as the one shown in Figure No. 8 is a typical style and resembles a small ceramic capacitor. The encapsulation protects the thermistor junction from physical damage from the environment.

Figure No. 8 – Thermistor and Its Electrical Symbol

An example of thermistor resistance versus temperature characteristics is shown in Table No. 1 below.

Temp (°C)	Resistance (Ohms)
25	10000
26	9572
27	9165
28	8777
29	8408
30	8056
35	6530
40	5325
45	4367
50	3601
55	2985
60	2487
65	2082
70	1751
75	1480
80	1256
85	1070
90	916
95	787

Table No. 1 – Thermistor Temperature versus Resistance

Thermistors provide good accuracy (typically around ±0.27 deg F) because of the fairly significant change in their resistance over a relatively small change in their temperature, as observed in Table No. 1 above. Like thermocouples, there is no mechanical movement involved and so they offer very good reliability. They are also very inexpensive compared to most other temperature sensors; and they offer good stability and repeatability.

A disadvantage of thermistors is the non-linear relation of their resistance and temperature. The thermistor's resistance-to-temperature relationship is mathematically expressed by the Steinhart & Hart equation

$$T = 1 / (a + b*\ln (R) + c*\ln(R)^3)$$

with a, b and c being constants; ln = natural log; R = thermistor resistance in ohms; and T = the absolute temperature expressed in degrees Kelvin

The upper and lower temperature limits in which thermistors may be used in applications is generally considered to be in the range of -100 degrees to 600 degrees F.

Their very compact size makes them somewhat ideal for use in monitoring temperature in very confined spaces, such as at motor windings or bearings

Resistance Temperature Detectors (RTDs)

The third type of electronic temperature sensor that we will discuss is the resistance temperature detector, which is typically referred to by the acronym “RTD”. The application of the tendency of electrical conductors to increase their electrical resistance with a rise in temperature was first identified by Sir William Siemens in 1871. In 1885, Calender-Van Duesen invented the platinum resistance temperature detector.

Most RTD sensing elements consist of a length of very fine coiled wire that is wrapped around a ceramic or glass insulated core. The fine wire of the element tends to be very fragile, so it is often enclosed within a protective metal probe referred to as a “sheath”. The wire or thin film sensing portion of the RTD is most commonly made of either platinum, nickel, or copper.

Compared to thermistors, RTDs tend to be less sensitive to small temperature changes and have a slower response time. RTDs in industrial applications are rarely used for measurement above temperatures of 1,220 degrees F (660 °C).

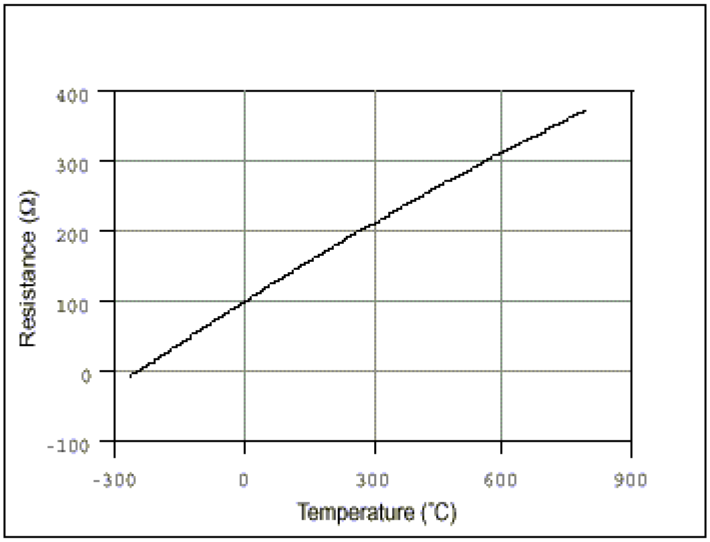

Chart No. 2 – Platinum RTD Resistance versus Temperature

The resistance of the RTD sensor is dependent upon its temperature and the type of wire wound element or thin film sensing material. Note that in Chart No. 2 the platinum RTD has a resistance of 100 ohms at zero degrees centigrade. Platinum RTDs have an accuracy of approximately ±0.1 °C. By comparison, a nickel RTD would typically have a resistance of 120 ohms at zero degrees centigrade and an accuracy of approximately ±0.5 °C.

Depending upon the specific type of application, RTDs are commercially available in various configurations that are largely dependent upon the environment in which they will be used. In harsh or hazardous environments the sensor may be enclosed in stainless steel sheaths or wells and the electrical terminations may be enclosed within an explosion-rated "head" such as those illustrated in Figure No. 9 below.

Figure No. 9 – Various RTD Configurations

Similar protective sheath and termination head configurations shown in Figure No. 8 and described above for RTDs are also available for thermistors and/or thermocouples.

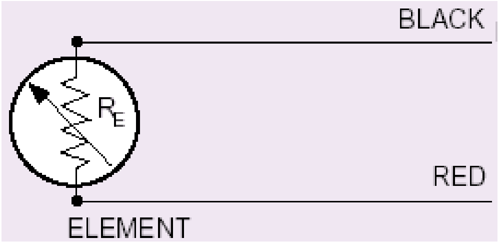

Figure No. 10 – 2-wire RTD Electrical Symbol

The simplest resistance thermometer configuration uses two wires (refer to Figure No. 10) and is only used when high accuracy is not required. In a two-wire configuration the resistance of the signal wires is added to the resistance of the sensor, adding some degree of error to the measured resistance value (signal).

A three or four-wire configuration provides greater measurement accuracy using one or two “compensating wires” in addition to the pair of RTD signal wires between the sensor element and the measurement circuit, which is typically a “Wheatstone Bridge” circuit such as that appearing in Figure No. 11. The four-wire configuration is the most accurate since it reduces more of the signal wire resistance error than a 2- or 3-wire configuration.

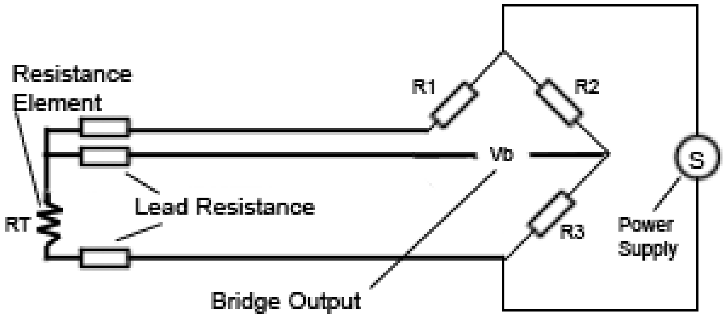

Figure No. 11 – Wheatstone Bridge Circuit

A Wheatstone Bridge, named after its creator, is essentially an electronic “bridge” circuit that acts as a signal transducer by producing an electrical output signal (voltage) that varies in response to an imbalanced condition of the resistor bridge. The RTD acts as one leg of the resistor bridge circuit. As the temperature of the RTD varies, its resistance varies, causing an increase or decrease in the balance of the resistor bridge. More information regarding RTD bridge circuits, and how they are configured for 2, 3 and 4-wire RTDS, can be found by going to http://www.tempco.com/Sensors/rtd_circuits.htm

Conditions that Affect Electronic Temperature Sensor Accuracy

There are a number of conditions that may adversely affect the accuracy of an electronic temperature sensor. They include:

- Placement of the sensor in relation to the measured temperature variable
- Exposure of the sensor to other environmental conditions
- Proper selection and application of the sensor to be used
- Proper wiring, shielding and grounding of the signal wires

Proper placement of a temperature sensor or temperature sensor array (multiple sensors) is crucial. The proper approach is simple: put the sensor, whenever possible, at the best location to sense the temperature that you want to measure. The thermocouple junction, thermistor and RTD are all very small in size and therefore are measuring temperature precisely where they are in contact with the measured variable (air or surface temperature of the object in contact with the sensor). Depending on such conditions as convection, stratification, thermal conductance and radiant heat energy, moving a sensor even a fraction of an inch one way or another can significantly impact the measurement.

When a sensor is installed in a protective metal well, such as the one shown in Figure No. 12, it is important that the sensor itself be directly in contact with the well, so that good thermal conductance occurs from the measured fluid (steam, water, oil, etc…) outside the well through the metallic wall of the well and into the sensor itself. This can be more readily accomplished by applying a thermally conductive grease between the sensor and interior surface of the well (thermal grease is a far better conductor of heat than an air gap) or by utilizing spring tension to press the sensor against the wall or end of the well. Both of those items are commercially available. Failure to do so can substantially slow down the response time of the sensor to changes in the temperature of the measured variable (sometimes referred to as “lag time”), or result in measurement error. Response time is often critical in control system applications. Thermocouples are inherently more responsive than RTDs.

Figure No. 12 – Thermowell (left) and Sensor with Termination Head (right)

Exposure of the sensor *to other environmental conditions* not only influences the measurement accuracy; but also plays a significant role in the reliability and life expectancy of the sensor. The wire wound element of an RTD, for example, is very fragile. Therefore, installing an RTD in a location where there is substantial vibration could potentially shorten the life of the sensor. It should be noted that when an RTD fails, it typically fails in an “open” (infinite resistance) condition. In a commercial building environment, the sensor may not need to be installed in a stainless steel sheath and be equipped with a weather-proof, explosion-rated termination head. However, municipal buildings or industrial facilities where acidic or caustic materials may be present, where vibration may be significant, and where the risk of physical damage is potentially high, the added expense of protecting the sensor may pay off in extended life expectancy and reliability.

Proper wiring, shielding and grounding can prevent occurrences of ground loops or imposed signal error on the sensor wires. Ground loop conditions occur when the ground conductor of signal wires are grounded at more than one end of the conductors. The ground potential can be different at each end of a long run of wire. By grounding the conductor at each end, a circuit is completed and the voltage differential between the two ground points is imposed on the ground conductor or shield. Since the ground reference is no longer at ground for a given location, the difference in ground potential becomes the error (also referred to as "offset" of the signal).

A ground loop occurs when there is more than one ground connection path between two pieces of equipment. The duplicate ground paths form the equivalent of a loop antenna which very efficiently picks up interference currents. Lead resistance transforms these currents into voltage fluctuations. As a consequence of ground-loop induced voltages, the ground reference in the system is no longer a stable potential, so signals ride on the noise. The noise becomes part of the signal.

Proper selection of a sensor requires factoring in the following things during the selection process:

- Will the sensor be exposed to a harsh environment?
- Will the sensor be installed within a hazardous environment?
- How critical is its function if it were to fail?
- What level of accuracy and repeatability are needed?
- What kind of response time is needed?
- How long must the sensor probe be?
- What style of temperature probe is needed?
- What is the availability of spare or replacement sensors?
- What is the cost of the sensor?

Note that the cost consideration is at the bottom of the list. As important as cost may be, the cost will largely be driven by the type of sensor that is needed to properly fit the application. Little money is saved on a sensor that is cheaper but inadequate for the application and fails within a matter of days, weeks or months of being installed and perhaps was never accurate in the first place.

Accuracy and Repeatability

So what are accuracy and repeatability as they relate to temperature measurement?

Accuracy is a term used to specify how close the measurement value will be to the actual temperature of the fluid or surface that is being measured. You will often see accuracy ratings that are in a plus and minus range. For example: the specification of a particular sensor has a stated accuracy that is ±1 percent of the range. So for a sensor having a range of 100 degrees to 600 degrees F its stated accuracy will be ±5 degrees F. That may or may not be accurate enough for a given application. Accuracy can vary due to any number of factors that include: the type of sensor used; sensor placement; and signal error introduced by the signal wiring between the sensor and display (or recording device – such as a data logger) and the error attributable to the signal transducer (if needed) and the display or recording device itself.

Repeatability is synonymous with precision - the ability of the sensor to exhibit the same value each time that it is sensing the same temperature. Repeatability is independent of accuracy. If the repeatability of a sensor is very good and the sensor happens to be, say inaccurate by 2 degrees F, then it will always provide the same measurement and be consistently inaccurate by 2 degrees. This repeatable inaccuracy is sometimes referred to as the "offset".

Pyrometers

A pyrometer is another type of temperature measuring instrument that typically uses a thermocouple that is either placed directly inside an oven or furnace or directly on the surface of the item for which temperature is to be measured. It was invented by Pieter van Musschenbroek in the early 1700s.

There are numerous types of thermocouple style pyrometers commercially available that can be used to accurately measure temperatures as high as 1500 °C. A typical modern day digital thermocouple-style pyrometer is shown in Figure No. 13.

Figure No. 13 – Handheld Thermocouple-Style Digital Pyrometer

There is also an instrument called a radiation pyrometer, which is a type of "non-contact" instrument for measuring temperatures that are above 600 °C. They are typically used to measure surface temperature of red hot metals, ceramics, glass, etc. in a mill, foundry, or processing plant.

A relatively common non-contact pyrometers is the "absorption-emission pyrometer" which is a thermometer used to determine gas temperature from measurement of the thermal radiation that is emitted by a calibrated reference source before and after this radiation has passed through and been partially absorbed by the gas.

Another type of pyrometer instrument that has been largely replaced by infrared technology is the “Disappearing Filament Pyrometer”, or DFP, which was used to measure the temperature of incandescent metals. To use this method of measurement, you would look through the pyrometer at the glowing metal, and manually turn a dial that adjusts the temperature of a glowing filament that is projected into your field of view. Once the color of the observed filament matched that of the glowing metal, you would read the equivalent temperature from a scale that was located on the filament color adjusting dial. DFPs measurement was somewhat subjective, relying a lot on operator judgment in deciding when the filament had “disappeared”. This dated technology generally produced a “ballpark” temperature. It is still worth mentioning the older pyrometer technologies since they were used for a good number of years before the development of cost-effective infrared technology.

Infrared Temperature Measurement

A much more recent method of temperature measurement, and the only “non-contact” type of temperature measurement that we will discuss in this course, is infrared temperature detection; also referred to as infrared thermometers. As its name suggests, this technology employs measurement of infrared radiation produced by an object when that object is warmer than absolute zero. This technology utilizes an optical lens to focus the infrared (IR) energy onto an infrared detector, which converts the detected energy to an industry standard electrical signal that can be displayed in standard temperature units. The quality of these instruments has improved substantially while their cost has decreased substantially in recent years.

Infrared thermometers were initially used for research and industrial applications that required relatively accurate measurement without any direct contact of the sensor with the object or substance of which the temperature was being measured. Often this was to avoid potential contamination of a product; destruction of a standard “contact” type of sensor – which would begin to melt at very high temperatures even when sheathed in stainless steel; or badly corrode (oxidize) due to aggressive acids or caustics. They were also used to measure the surface temperature of things such as steam pipes that were not easily accessible without a powered lift or ladder. Their use has broadened as many forensic engineers and service technicians now use these instruments largely for obtaining accurate surface temperature measurements of such things as light fixtures, electrical panels, junction boxes, plugged steam traps, vessels, conduits and pipe lines that are located in relatively inaccessible locations.

Figure No. 14 – Examples of Handheld Portable and Stationary Infrared Thermometers

Substantial advancements in infrared thermometer accuracy and reliability have occurred through the introduction of "selective filtering" of the incoming IR signal; which was made possible by the development of more sensitive detectors, such as that shown on the left in Figure No. 15, and signal amplifiers that have greater stability.

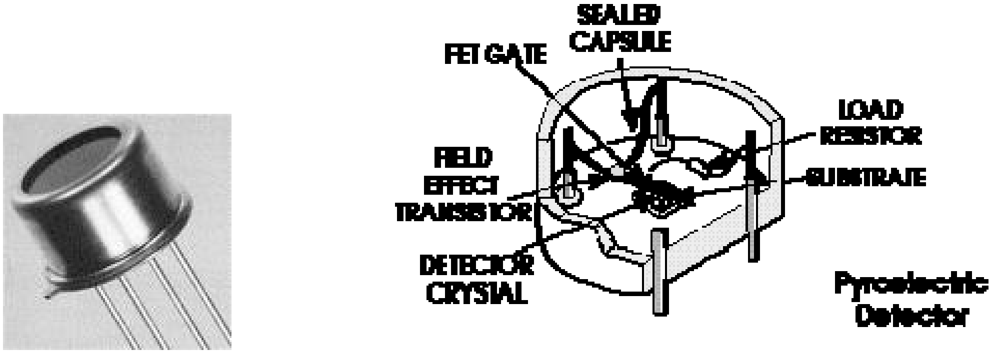

Figure No. 15 – Infrared Sensor

Stationary or fixed position infrared detectors are used in situations where the product whose temperature is to be measured passes in front of the instrument on a material handling system such as a conveyor, such as the instrument shown on the right in Figure No. 14.

Change-of-State Temperature Indicator Devices

Worth mentioning is one other type of temperature sensor category, referred to as "change-of-state" devices. Change-of-state temperature detectors generally consist of labels, crayons, lacquers or liquid crystal displays whose appearance changes (often a color change) when the sensed temperature reaches a certain point. For those of you old enough to remember the "mood rings" fad of the 70s, the color of the ring would change in response to changes in body temperature (more specifically the finger temperature). Some change of state devices function in much the same manner. Response time typically takes several minutes, so these devices are pretty slow in comparison to an electronic temperature sensing device. Accuracy is less than that of most other types of sensors. Some indicator changes are irreversible in that they change color with a change in temperature and then remain in that same condition - even if the temperature condition reverts back to its original condition. Change-of-state sensors are most useful as a visual confirmation that the temperature of a piece of equipment or surface temperature of an object has, or has not, exceeded a certain level. They are generally inexpensive.

One type of change-of-state indicator label technology uses multiple waxed layers, with the upper layers formed using a mixture of viscous material and powdered petroleum wax that melts at a selectively preset temperature to expose the bottom, “indicator” layer that is in contact with the object being “sensed”.

Another type of change-of-state temperature detector, such as that appearing in Figure No. 16 uses rod-shaped thermotropic liquid crystals that react to changes in temperature. The liquid crystal molecules are very sensitive such that they change their position or distort their shape according to certain changes in temperature. This temperature responsive change in their molecular structure affects the wavelengths of light that is absorbed or reflected by the liquid crystals, resulting in an observed change in color.

Figure No. 16 – Temperature Indicating Label

In summary, the technology of temperature measurement has been around for several centuries and has advanced considerably in terms of sensing accuracy, reliability, and methodology. It is interesting that most of these temperature measurement devices are still commercially available; attesting to their unique usefulness in a wide range of applications. There are a number of parameters to consider when selecting the appropriate temperature measurement device. Determine exactly what it is you want to measure, identify the optimum measurement location, make note of the conditions (environment) to which the device will be exposed and how accurate and repeatable it must be to meet your needs, and then select the most cost-effective device for your application.