Sensors | Whitepaper

Selecting a Superior Sensing Solution

MINCO

Background

Of all environmental parameters, temperature is the most commonly measured. We each have a good idea of what temperature is. After all, our own bodies need to be within a narrow temperature range for comfort and provide feedback of relative hot and cold.

While our general concept of temperature is clear, the science behind temperature is less understood and can be challenging to apply. Temperature is a measure of the hotness or coldness of an object linked to its average kinetic energy. An increase in kinetic energy within a system is observed as an increase in the hotness. Kinetic energy is the energy of motion, i.e. molecular vibration, rotation or translation (point A to point B). Within a physical system, objects that are hotter will spontaneously attempt to achieve a state of equilibrium with objects that are colder by transfer of kinetic energy. Not all energy is kinetic but may exist in several states of potential energy as position (gravitational), electrical, chemical or nuclear energy.

The transfer of kinetic energy between objects may occur through conduction (direct thermal contact between objects), convection (transfer to a fluid medium, liquid or gas, creating current that flows to another object) or radiation (objects emit rays or waves of particles that strike and are absorbed by another object). The process of achieving thermal equilibrium may be improved or impeded through manipulating the transfer mechanisms.

Thermometry is based on a principle of thermodynamics that states when two objects are separately in thermal equilibrium with a third, they are all at the same temperature. One of the objects can be a thermometer calibrated by being brought into equilibrium with a stable thermal environment of known temperature (second object) and then used to determine the temperature of a third object when brought in thermal equilibrium with it. We assign a repeatable value to the measure of the kinetic energy of a body and place it on a reference scale in order to be useful.

One of the early scales was the Fahrenheit scale (1724), based on the phase transitions of pure water under normal atmosphere. Several stories exist about how Fahrenheit's scale points were determined, among them 0°F being the freezing point of equal mixtures of salt and water (or the lowest outdoor temperature measured where Fahrenheit lived) and 100°F being what Fahrenheit believed body temperature to be. The ice point of pure water (transition to solid) was defined as 32 degrees and the boiling point of pure water (transition to vapor) was defined as 212 degrees. Other temperatures are scaled from these points. Celsius redefined the ice and boiling points as 0 and 100 degrees in a new scale also referred to as Centigrade for its 100 gradations.

Other scales, called absolute scales, begin with their 0 at the theoretical absolute zero where all kinetic energy ceases to exist. Absolute zero has never been achieved in reality, but modern technology has created temperatures within a fractional degree of absolute zero where even the speed of light slows to a crawl. Determination of absolute zero was calculated from the application of the first two laws of thermodynamics into a temperature scale of an ideal gas in a constant volume hydrogen thermometer. This thermometer was also used by Lord Kelvin to measure the ice and boiling point of water to create the same unit size as Celsius for the Kelvin absolute scale (0K = -273.15°C). The Rankine absolute scale (0°R = −459.67°F) uses the same unit size as Fahrenheit.

The Thermodynamic Scale is based on properties of ideal gas in a gas thermometer for measurement. One of the most important and very accurately reproducible temperatures is the triple point of water where the water exists simultaneously in three phases of solid, liquid and gas at 0.01°C. The triple point of water is one example of a *fixed point*, where a pure substance reaches a state of equilibrium between 2 or 3 phases at a specific temperature.

Another example is the freezing point of tin, which occurs at 231.928°C. All temperatures outside of these fixed points are actually interpolations of value based on the properties of various practical thermometers precisely calibrated from these fixed points. A consortium of international laboratories meets regularly to refine the temperature scale as technology improves measurement accuracy.

The current internationally accepted standard for defining temperature is the International Temperature Scale of 1990 (ITS-90). The interpolating standard used for the lowest cryogenic temperatures is a Helium constant volume gas thermometer, transitioning to a platinum resistance thermometer from the triple point of equilibrium hydrogen (-259.3467°C) to the freezing point of silver (961.78°C) and to radiation thermometry for higher temperatures. ITS-90 is very nearly the same as the former standard IPTS-68 up to 400°C, but has more significant variation above 400°C. At 600°C the ITS-90 value is 0.1°C lower than IPTS-68, then begins to shift upward to 0.4°C higher than IPTS-68 at 750°C. Instruments that read industrial platinum resistance thermometers may utilize the Callendar-Van Dusen equation to determine temperature from measured resistance, based on the IEC 60751 standard.

How Can We Measure Temperature?

Thermometers can be broken down into two broad categories depending on how they take readings, contact and non-contact.

Contact Thermometers

Outside of radiation thermometers, the method of measuring temperature involves contact between the sensor and the object being measured. Every contact sensor is only capable of measuring its own temperature and must rely on the thermodynamic principle of achieving equilibrium with the object to be measured in order to infer the temperature of the object. Most temperatures being measured in real applications are not static (heat is constantly being transferred to or from parts of the object), not isothermal (temperatures are different across the object) and equilibrium is never really achieved. Outside of controlled laboratory environments, temperature measurement is a snapshot of a localized condition.

The choice of sensors used in measurement and their location in the system can have a significant impact on the ability to measure the temperature of greatest interest:

- If the mass of the sensor is large relative to the object being measured, achieving equilibrium will shift the energy state of the object being measured.
- Temperature sensors are constructed with electrically insulating materials that impede heat transfer. Consequently, there will be a lag between the change in temperature in a system and the sensor achieving equilibrium with the system. The errors introduced by this lag become more pronounced with increased mass of the sensor and as temperature swings of the system increase.
- A sensor construction with the lowest internal mass and the least thermal resistance between the sensing element and the object measured will provide the most responsive tracking with a system temperature that is changing rapidly.
- A very small sensor construction will be capable of sensing a point of interest but cannot measure average temperature in a dynamic system. Average temperature is often optimal for control systems.
- The most responsive constructions may not provide sufficient ruggedness and protection from environmental conditions. For example, thermowells or thick wall metal cases may be required for strength but add “thermal mass”. Insulation may be needed for electrical isolation but impedes heat transfer to the sensing element.

- Sensors mounted to an object's surface may be affected by external environmental factors. Consider sensor and/or system designs to minimize the effects.
- Lead wires and sheaths that connect to the sensing element provide a thermally conductive path to the external environment. In slower responding sensors with shallow penetration of the object being measured, these paths can greatly impact measured temperature, particularly when the gradient is large between the system and the external environment.
- It may be desirable to deliberately slow down the sensor response to prevent false alarms in systems that are subject to transient environmental changes creating minimal impact on the system. For example, a fast-responding sensor could trip an overtemperature alarm simply by opening a medical refrigerator door to remove a bag of blood – even though the *contents* of the refrigerator remain below the critical temperature.

Contact sensor constructions have evolved into families of parts best suited for particular application parameters. Minco has several different broad categories of products designed for a variety of applications based on historical preferences. A new custom design or a modification to an existing design can improve performance for your application. Minco encourages an engineering review of objectives for your application to ensure optimal results.

No-Contact Thermometers

Every object above absolute zero emits radiation in a spectrum that is repeatable and proportional to its energy level (temperature) and the emissivity of its radiating surface (a black body has an emissivity of 1 and everything else is a fractional value). Non-contact Infrared (IR) thermometers are capable of sensing this radiation and compensate for known emissivity surfaces.

Non-contact thermometers are particularly useful when:

- Measuring beyond the temperature limits in which contact thermometers can operate reliably.
- Measurements need to be made remotely due to distance of separation between sensed system and monitoring location.
- There is movement of the sensed system relative to the monitoring location.
- Fast response measurements of low mass systems are required.

Various IR sensing systems use optics to focus the radiation on photoreceptors sensitive in the IR spectrum. The object being sensed should be larger than the field of view of the optics or other background radiation will be sensed and create error. The field of view can be selected in the instrument to be narrow for small objects, distant objects or when only an isolated measurement within the system is desired. A wide field of view can be selected for large or close measurements, or to represent the average temperature across the field of view. Typical recommendations are that the object be 50% larger than the field of view of the optics to provide a good average temperature.

Fiber optic sensors can use a glass fiber for long distance temperature readings and can actually have multiple fiber Bragg gratings along the same fiber. Each grating location may be exposed to different temperature points in the system and transmit each as a unique temperature measurement back to the control center through the glass fiber.

Types of Sensors

The four most common types of sensors are resistance temperature detectors (RTDs), thermistors, thermocouples and IC sensors.

Resistance Temperature Detectors

An RTD sensing element consists of a wire coil or deposited film of pure metal or precise metal alloy. The element's resistance increases with temperature in a known and repeatable manner. RTDs exhibit excellent accuracy over a wide temperature range. The platinum resistance thermometer is the primary interpolation instrument for temperatures defined by the ITS-90 international standard from -260°C to 962°C. Even ordinary industrial RTDs typically drift less than 0.1°C/year. Their repeatability, stability and wide temperature range are key factors in their frequent use as industrial temperature sensors.

Depending on measurement instrumentation, the voltage drop across an RTD typically provides a much larger output than a thermocouple. Platinum and copper RTDs produce a more linear response than thermocouples or thermistors and RTD non-linearities can be easily corrected through proper design of resistive bridge networks or smart electronics.

RTDs can be any metal or metal alloy conductor with repeatable temperature-dependent resistance. Many early commercialized RTDs employed copper, nickel or nickel-iron alloy fine wires for their low cost and ease of manufacture. Each of these was suitable over limited temperature spans that would not oxidize the fine element wires. Platinum wire elements were employed in higher end applications requiring extended temperature capability or laboratory performance. Wire element RTDs are most stable when the element wires are larger diameter, being less susceptible to effects of oxidation or the mechanical strains of packaging. On the other hand, it is desirable to have very fine element wires to increase the resistance (more sensitivity in ohms/degree), reduce sensor package size, and/or to keep the cost of a precious metal like platinum to a reasonable level.

RTD constructions vary widely at the simplest element level to complex packages. The most stable and accurate laboratory PRTs use element constructions of the purest platinum wire in a strain-free construction (free to expand and contract with temperature without effect of their supporting structure) and hermetically sealed. This type of construction provides the highest accuracy, best repeatability, and widest temperature capability – but is quite expensive, fairly delicate, and susceptible to shifting when mishandled.

Another approach for stability is to minimize strain by maintaining a platinum wire coil structure, but threading the coils within bores of a ceramic body (round mandrel). These bores can also be filled with mineral oxide to provide some ruggedness for handling. This construction maintains a wide temperature capability span (850°C), near laboratory accuracy and stability while dramatically reducing the cost of the element. The increased ruggedness allows the units to leave the lab for use in field conditions.

To maximize the ruggedness of a platinum RTD element for the most severe applications, the wire is no longer coiled, but wound onto a ceramic mandrel and overcoated with glass. All materials are selected to closely match the thermal coefficient of expansion (TCE) of the platinum wire. The element is no longer strain-free but works well within a more restricted temperature range (550°C). Completely encapsulating the element wire in a supporting structure makes the design very robust, capable of handling high levels of shock and vibration.

This construction introduces an effect called hysteresis when used at cold temperatures below -75°C. The materials supporting the platinum wire go through a transition phase that induces strain into the element, shifting the resistance slightly. Hysteresis is reversible, so when the temperature is brought back high enough, the strain is relieved and the element reverts to its original values. If thermally shocked at cryogenic temperatures and not used above room ambient temperatures, this construction would maintain its calibration for cold applications.

RTDs do not have to use wire for the sensing element. The majority of the platinum RTDs manufactured today are actually a thin film coating of platinum applied over a ceramic substrate, trimmed to tight resistance tolerances and overcoated with glass. Thin film RTDs can be supplied with leads for attachment to extension wires or as a surface mount component for attachment to printed circuits. Thin film RTDs drastically cut the cost of the sensing element through automating element manufacturing and use of very small amounts of precious platinum metal. Thin films maintain a high degree of ruggedness –

even to high temperatures (400°C or 600°C) – and greatly expand the practical applications for RTDs. Thin film RTDs are effectively point sensors, while wire wound RTDs can measure average temperature over large surfaces. There are still many applications that benefit from the greater performance of wire element RTDs for wider temperature spans, severe usage, and the natural ability of the RTD to average temperature over the entire element.

The element constructions described above are not typically used without further packaging. Most often, these elements end up in a protective sheath or can. The methods and materials for RTD assembly are many, and RTD performance characteristics can vary greatly depending on how it is packaged for the application. It is highly recommended that you review your intended application with a sensor expert to come up with the best performing design at the best cost. It is very important to understand the real objective of your temperature measurement and determine which sensor parameters are critical. Often there are conflicting requirements (e.g., fastest response time and ruggedness) that need to be sorted out to create an acceptable solution.

RTD elements do not have to be supported on ceramic. The wire elements can be placed within films of flexible laminates. The primary advantages of this type of construction are the ability to measure average temperature (by placing the element wire over a large surface), fast response time, and surface sensing (by using thin insulating films that are low mass and allow optimal heat transfer between the measured surface and the sensing element). RTDs constructed in a flexible package do compromise repeatability, stability, and temperature range. They have a practical upper temperature limit of 260°C. The flexibility of the package and mismatch in TCE between the element wire and the supporting structure impose strain on the element and, consequently, a shift in resistance.

In a two-wire measuring system, all lead wire resistance is added to the RTD measurements. RTDs connected to a reading instrument a foot or two away have generally little concern about lead wire resistance. High resistance RTDs will extend the range for two wire usage without significant error contribution. A 100-ohm platinum RTD will have a typical change in resistance of .38 Ω/°C, while a 1000-ohm platinum RTD will have a typical change in resistance of 3.8 Ω/°C. Minco even offers a 10000-ohm platinum RTD with a typical change in resistance of 38 Ω/°C. A typical RTD extension lead wire of AWG#18 will contribute .0065 Ω/foot (.013 Ω/two-lead foot) resistance. An instrument could be about 300 feet away from a 10000-ohm RTD with less than .1°C error, but only about 3 feet for a 100 Ω RTD. It is possible to calculate the temperature offset created by the two leads and take the offset into account at the instrument, but the lead wire is copper and will change slightly in resistance with ambient temperature as well. When lead wire resistance creates significant error, it is advisable to use 3 or 4 wire resistance measurement techniques to compensate for lead resistance.

The positioning of a sensor can greatly impact your process. Heaters or changing thermal loads impact the temperature of the system – requiring proper sensor positioning to best characterize the system. A sensor in intimate contact with a heater will respond quickly to changes in the heater temperature to prevent overshoot but may not achieve the desired process control. A sensor that is too isolated from the heat source may be measuring the wrong part of the process and will not adequately control the heater cycles, subjecting the system to wide temperature swings. It may be that no single point is the best representation of the system temperature and that an averaging sensor or multi-zone control is needed.

RTDs are a common choice for applications in chemical/petrochemical, process control, pharmaceutical, rotating equipment, critical environment HVAC/R, aircraft, and even automotive markets.

Thermocouples

A thermocouple consists of two wires of dissimilar metals joined together to form the measuring junction (welded, brazed, soldered, twisted). The other end of the sensor wires (usually terminated in the reading instrument), constitutes another junction called the reference junction. A thermoelectric potential (millivolt-level emf) is generated, proportional to the temperature difference between the two junctions. The reference junction is normally within an isothermal block containing a calibrated sensor (RTD, thermistor, or IC) to determine the actual reference junction temperature.

Published millivolt tables assume the reference junction is at 0°C but can be used for other reference junction temperatures by adding the measured voltage to the voltage that corresponds with the actual reference junction temperature. This is known as *reference junction compensation* or *cold junction compensation*. Voltage polarity indicates whether the measuring junction is at a higher or lower temperature than the reference junction. Although this works fine for most cases, the temperature non-linearity of thermocouple output could introduce error. For best accuracy, the CJC voltage should be added to the measured voltage to determine the actual temperature.

Thermocouples are made from a wide variety of wires resulting in many standards. The interchangeability of units is very dependent on the wires always having the same exact compositions. While one of the wires is often a pure metal like copper, iron or platinum, the other wire is typically an alloy of metals to provide the highest voltage output. Thermocouple materials are available in *standard tolerances* and *special tolerances* per ASTM E230/E230M but achieving accuracies within a few °C over a span will require individual calibration.

A thermocouple is inherently a point sensor at the measuring junction (assuming reference junction compensation). When it is desirable to average temperature over a surface, the thermocouple will average the output across multiple junctions of the same wire pair compositions, connected in parallel. Thermocouples connected in series are usually called thermopiles and do not provide an average temperature.

Thermocouples are simple and familiar. Designing them into systems, however, is complicated by the need for special extension wires and reference junction compensation. Thermocouple junctions other than precious metal wires are generally low cost – making them advantageous for some disposable sensing applications where the sensing material is sacrificed. Fused wire junctions having a single electrical connection in the sensing tip are innately rugged and resistant to shock and vibration damage. Thermocouples can be used reliably at much higher temperatures than RTDs, thermistors or IC sensors making them the preferred contact sensor for higher temperatures, particularly above 850°C.

Thermocouple junctions can be made with very small diameter wires and applied as exposed (bare) junctions to provide extremely rapid time response with little thermal loading on low mass objects being measured. The small wires are fragile and it is common practice to use the fine wires for only a short distance before fusing the wires to larger diameter wire for handling.

Most thermocouples do not have bare junctions but are protected in a sheath or insulating materials in either grounded or ungrounded packages. Grounded junctions are in metal-to-metal contact with the protective sheath at the sensing tip to improve the speed of response, while still protecting the junction from the environment. Grounded junctions can create electrical ground loops that may introduce error in temperature readings unless the measuring instrument uses voltage isolation (optocouplers) on the inputs. Ungrounded junctions electrically isolate the measuring junction wires from the case through packing in insulating materials like epoxies or mineral oxides. The insulation prevents ground loops and allows lower cost measuring instruments (non-isolated) to be employed for reading the sensors. This type of packaging slows the response time of the measuring junction – in fact, RTD constructions can be made to respond faster as the probe diameter increases. It also adds a potential error mechanism if the insulation value in the sensing tip breaks down over time and shunts to ground due to moisture absorption or cracking of the insulation.

Since a thermocouple requires the use of a reference junction sensor (RTD, thermistor or IC) and associated electronics to combine the readings of the measuring junction and reference junction, the system cost has no advantage over RTDs or thermistors with their associated electronics, or over ICs with their built-in electronics. Thermocouple output is also non-linear (emf per degree varies with temperature rather than being a constant). In many applications that cover small to moderate temperature spans, the thermocouple output is assumed linear and the resulting errors acceptable but the electronic instrument reading the thermocouple could be characterized to compensate for the non-linearity or employ linearizing signal conditioners.

Thermocouples work best when distances between the measuring junction and the instrument are small, as the cost to deploy them in longer runs becomes significant. Thermocouples require extension leads of the same compositions, i.e., copper wire must go to copper wire and constantan wire to constantan wire. If the junctions are not similar metals, there will be new thermocouple junctions created while introducing stray voltages in the measurement circuit – ultimately resulting in temperature measurement error. For example, adding copper extension wires to a copper-constantan thermocouple will make one connection copper-copper (no emf generated from this junction) and the other junction copper-constantan (same as the sensing tip but will create an additional emf for any temperature difference between the two junctions).

You may also want to use larger extension wires to reduce lead wire resistance that can affect voltage readings over large distances. If terminal blocks are employed to transition from the sensing wires to extension wires, the blocks should be isothermal, or have terminals that match the connecting wire compositions. Again, in the case of the copper-constantan junction, a copper terminal block would create copper-copper, copper-copper junctions on one side and constantan-copper, copper-constantan junctions on the other. If all junctions are isothermal, there is no generated voltage. Installing long runs of larger diameter extension wires and special terminal blocks can be fairly expensive, resulting in a quick payback for a signal conditioning alternative (i.e., temperature transmitter).

Another consideration for the use of signal conditioning near the measuring junction is that the signals from thermocouples are very small and susceptible to electrical noise and interference.

Thermocouples are commonly found in applications within the chemical/petrochemical, metals, process control, food/beverage, rotating equipment and semiconductor equipment markets.

Thermistors

A thermistor is a ***Therm***ally Sensitive Res***istor*** device consisting of metal oxides formed into a bead, rod, or disc, and encapsulated in epoxy or glass. A typical thermistor shows a large negative temperature coefficient of resistance, where resistance drops dramatically and non-linearly with increasing temperature. Sensitivity is many times that of RTDs, but the useful temperature range is generally limited to 150°C (although there are designs that can tolerate up to 300°C). Some manufacturers offer thermistors with positive coefficients. Linearized models are also available.

Thermistors have many material families and base resistances that generate a multitude of different resistance vs. temperature curves. There are wide variations of performance and price between thermistors from different sources. One of the difficulties that users of thermistors must face is that the curves of one source are difficult to match exactly from other suppliers – although in most cases, other suppliers can get you something close.

Basic thermistors are quite inexpensive. However, models with tighter interchangeability or extended temperature ranges often cost more than equivalent spec RTDs. Thermistors typically have a base resistance much greater than an RTD – 10,000 and 50,000 ohms at 25°C are very common. This gives them great sensitivity, but also makes them prone to self-heating error – where the power required to measure the device creates heat, making the sensor temperature higher than the object it's trying to measure. A thermistor bead can be made the size of a pin head for small area sensing and fast response measurement. Thermistors are also available in small surface mount configurations for placement on printed circuits.

The lowest cost thermistors are coated with epoxy to seal the metal oxides from the environment. This is acceptable for many applications, but the best hermetic seal is a glass coating. Glass coated thermistors are much less susceptible to contamination of the metal oxides and subsequent resistance shifts due to environment. However, it is important to exercise care in the installation of any thermistor bead. If the hermetic seal is broken through damage to the epoxy or glass at the lead exit, it will be subject to moisture intrusion that changes the measured resistance.

Thermistors work best when you are trying to control or measure temperature within a narrow span. Thermistors are commonly found in applications within automotive, telecommunications, medical devices, HVAC/R, appliances, computing and aerospace markets.

IC Sensors

Integrated Circuit (IC) sensors are manufactured in silicon chip form where semiconductor diodes exhibit a voltage to current relationship that is temperature sensitive. Because these are manufactured as ICs, they are manufactured with various integrated signal processing or signal conditioning circuits in the chip. With the versatility of the on-board signal processing, the outputs of IC sensors may be generated as analog millivolt (scaled 10.0 mV/°C or 10.0 mV/°F), analog current (10mA/°C), logic (on or off state) or digital (8 to16 bit data packets representing temperature). The signal processing also ensures that the output is linear with temperature change.

IC sensors are fairly low cost, especially when the cost of associated signal conditioning circuits is added to other contact sensing technologies. IC sensors are available with pins for placement into probe cases or surface mount configurations for packaging on printed circuit boards. IC sensors also have a limited operating temperature range and are generally not able to operate above 150°C. The accuracy of IC sensors is not as good as RTDs or thermistors, typically ±1.0°C at calibration temperature. Because the IC sensor contains an active electronic circuit that generates heat, a built-in offset attempts to compensate for self-heating errors, but this is not consistent across the temperature range and all environments. Self-heating worsens when ICs are built into plastic chip packages or when assembled into insulated probe packages.

IC sensors are commonly found within computing, cellular communications equipment, medical devices, and industrial controls.

Non-Electronic Thermometers

If all you need is local temperature indication or an indicator when exceeding a specific temperature, there are many more forms of temperature sensing, including:

- Labels, crayons, pellets and varnishes that can be applied to the object. When the critical temperature is exceeded, materials undergo a visible phase change (e.g., melting). Crayons, pellets, and varnish change physical appearance. Printing and/or color indication on labels is exposed when the overcoat melts and gets absorbed into the underlying label material.
- Liquid-in-glass thermometers push an opaque fluid from a reservoir up a calibrated channel in the glass.
- Liquid crystal thermometers use thermochromic liquid crystals that align to reflect a different portion of the light spectrum as temperatures move through their sensitive zone, going from black to red to green to blue and back to black.
- Gas and liquid-filled thermometers move a dial gauge through a calibrated arc as the temperature rises or falls.
- Bimetal thermometers utilize the difference in thermal expansion of bonded metal strips to move a dial through a calibrated arc that correlates to temperature.

Each of these options provide local temperature indication without the need for line power or batteries.

	Thermocouple	Resistance Thermometer (RTD)	Thermistor	IC Sensor	Infrared
Operating Principle	Generates mV EMF proportional to temperature differential	Passive variable resistor, increases with temperature	Passive variable resistor, decreases with resistance	Semiconductor diodes have temperature sensitive voltage to current	Bodies above absolute zero radiate energy
Temperature Range	-250 °C to +1800 °C	-200 °C to +850 °C	-60 °C to 300 °C	-55 °C to +150 °C	-50 °C to 3000 °C
Sensor cost	Low	Wire — high Thin film — low	Low	Moderate	Very high
Measurement Area	Point	Averages across element	Point	Point	Varies with optics
Sensor size	Fine exposed junctions down to 0.25mm	Large by design down to 2.0mm square	Small to 0.5mm	Down to 2mm IC packages	Typically handheld
Accuracy	Less Accurate	Lab standards define temperature scale	Lab models available with high accuracy	Less Accurate	Less Accurate
Repeatability	OK	Good	Good	OK	Good
Stability (Drift)	OK for limited time	Good	Good	OK	Good
Hysteresis	Excellent	Good	Good	Good	Good
Vibration	Very Good	Good	Good	OK	OK
Linearity	Non-Linear	Linear	Non-Linear	Linear	OK
Reference Junction	Required	Not Required	Not Required	Not Required	Not Required
Lead Wire Resistance	No Problem	Generally needs to be evaluated	Generally, no problem	No Problem	Not Required
Contact Required	Yes	Yes	Yes	Yes	No
Response	Fast	Slow to Medium	Medium	Slower	Fast

Other Considerations

Though choosing contact vs. non-contact and sensor technology may be paramount, there are other factors to consider when choosing a sensing solution:

Package Constructions — Cases, Sheath Materials, Laminates

Sensors come in a multitude of different shapes and sizes to fit a multitude of different applications. While operating temperature may dictate the packaging materials, the mounting location often determines size and shape:

- Flat: for positioning between stator windings in a motor/generator.
- Small, low mass: for satellites.
- Tip-sensitive probe: for contacting a bearing race but anchored to the housing.
- Long, bendable: for average temperature in a duct.
- Heavy wall probe (thermowell): for fluid in a pipe at high velocity.
- Miniature, robust: for shoes in fluid film bearings.
- Pipe threads: for fluid-tight seal on storage tanks.
- Adhesive backed: for stick and sense simplicity.
- and many more. . .

Agency Specifications

When a process or environment is potentially flammable or explosive, it is considered a hazardous area. To avert a catastrophic incident, components and systems capable of igniting the flammable substance are heavily scrutinized for safety measures. Despite regulatory similarities, each country typically has its own set of requirements – either as a published electrical code or as occupational safety regulations. Each country also maintains a list of recognized agencies (laboratories) from which they accept certification that the products/systems have been adequately evaluated or tested to insure safe operation within the specified environmental parameters. In the United States, some well- known examples of such laboratories are UL (Underwriters Laboratories), FM (Factory Mutual), and CSA (Canadian Standards Association).

The widely accepted method of classifying hazardous areas, sometimes called the “Zone” system, defines 3 zones according to the probability of a flammable substance being present under normal operating conditions. A defined area where flammable material is present continuously or for long periods is designated Zone 0 (gas) or Zone 20 (dust/fiber). In contrast, Zone 2 (gas) and Zone 22 (dust/fiber) designate areas where a flammable substance is present briefly or due to an abnormal condition (leak, spill, etc.). Zone 1 (gas) and Zone 21 (dust/fiber) covers areas with greater probability of flammable substance presence than Zone 2/22, but less than Zone 0/20.

The second criteria for hazardous area classification is a flammable substance. There are three groups: Group I for underground materials such as coal dust and firedamp; Group II for above ground gases – further categorized into three subgroups; and Group III for flammable dust and fibers. North America accepts the zone classification system, but also recognizes an alternative often called the "Class/Division" system. This system uses two Divisions instead of three Zones to define the probability of a flammable substance being present, then Classes and Groups to categorize flammable materials.

There are a number of protection methods designed to prevent ignition in a hazardous area that are far beyond the scope of this whitepaper. However, be advised that not all protection methods are created equal. Great attention should be given to choosing a protection method to insure it is compliant with the requirements of the area classification. A good place to start is the local electrical code of the operation destination.

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