# A Detail Review on Temperature Measurement Techniques

Mr. Rajkishor Singh, Mr. Jitendra Kumar Singh Jadon, Mr. Anil Kumar Joshi, Mr. Ravi Kr. Bhatnagar
Shobhit Institute of Engineering and Technology (Deemed to be University), Meerut
Email Id-rajkishore@shobhituniversity.ac.in, jitendra@shobhituniversity.ac.in, anil.joshi@shobhituniversity.ac.in, ravi.bhatnagar@shobhituniversity.ac.in

***ABSTRACT: In today's industrial world, temperature measurement serves a broad range of requirements and applications. To satisfy this diverse set of requirements, the process controls sector has created a vast variety of sensors and devices. You will get the chance to learn about the principles and applications of a variety of common transducers in this experiment, as well as conduct an experiment with a selection of these devices. For most mechanical engineers, temperature is a crucial and frequently monitored quantity. Invasive measurement, in which the monitoring device is placed in the medium of interest, and noninvasive measurement, in which the monitoring system monitors the medium of interest remotely, are both possible using a number of methods. In this post, we'll look at both basic methods and specialized instruments for specific purposes. The problems of measuring criteria are discussed, including accuracy, thermal disturbance, and calibration. A selection guide is given based on the relative advantages of various methods.***

***KEYWORDS: Fluorescence, Noise Thermometry, Temperature, Temperature Measurement, Thermal Calibration.***

## INTRODUCTION

One of the most basic thermodynamic characteristics is temperature. The kelvin temperature is defined as equal to the thermodynamic temperature minus 273.15 and the magnitude of 1 °C is numerically equivalent to 1 K, in addition to the thermodynamic temperature [1]. ITS-90, the current international temperature scale, specifies a temperature scale with five overlapping ranges. Temperature may be measured using a variety of methods, including thermoelectricity, temperature-dependent change in electrical conductor resistance, fluorescence, and spectral properties. Furthermore, the temperature measuring criteria may enable direct contact with the medium. If this isn't feasible or desired, a noninvasive technique may be employed instead. The different measurement methods may be divided into three groups for ease of understanding, based on the type of contact between the measuring instrument and the solid, liquid, or gaseous medium of interest [2]. Temperature measurement is expected to account for 75 percent to 80 percent of the global sensor market. Accuracy, sensitivity, life, size, cost, manufacturing restrictions, dynamic response, operating temperature, and resilience may all be factors to consider when choosing a temperature measurement technique. The accuracy of a measuring methodology is influenced by a variety of variables, including calibration against an absolute temperature scale, thermal disturbance caused by installation methods, transducer output monitoring, and instability effects. Secs takes into account these factors. Installing a physical sensor on or inside a component, such as a turbine blade, or a medium of concern, such as exhaust gas, is known as invasive instrumentation [3].

Invasive instrumentation comes in a wide variety of forms: gas and liquid-in-glass thermometers, thermocouple and resistance temperature devices are just a few examples. While some of these instruments, such as gas thermometers, are better suited to a calibration lab, they are included here for completeness and to define the accuracy of other sensors [4]. The use of intrusive equipment causes a disturbance, which shows up as a difference between the temperature being measured and the temperature that would exist if the apparatus were not there. The balance of convective heat transfer from the gas to the sensor surface, conduction in the sensor itself and its supports and connections, and radiative heat transfer between the sensor and its surroundings determines the temperature reached, for example, by an invasive instrument in contact with a gas stream. The thermal distortion induced by the installation of thermocouple wires encased in ceramic paste in a steel block for steady state circumstances [5]. For the boundary conditions set, the temperature profiles would have been horizontal prior to installation. The estimated temperature in the center of the ceramic-filled tube is 373.6 K. In the absence of the thermal distortion, the temperature at this point would be 377.4 K. Temperature may be measured by using the expansion of materials as a function of temperature. Fluid thermometry encompasses a wide variety of devices, including calibration gas thermometers with constant volume and constant pressure and liquid-in-glass thermometers [6]. Solid expansion is utilized in bimetallic strips and other devices. The ideal gas law is the foundation of gas thermometry; the temperature is calculated from pressure and or volume measurements. When used in this manner, the accuracy is determined by many factors, including the value of the gas constant.

Liquid-in-glass thermometers may be calibrated at a variety of fixed locations, and a scale can be attached to a stem holding the capillary tube to show the temperature's range and value. The precision of industrial glass thermometers varies depending on the instrument, with temperatures ranging from 60.01 to 64 °C. 25 60.005 °C precision is possible with laboratory glass thermometers. Non-uniformities in the manufacturing of the capillary bore may cause inaccuracy [7]. The device will seem correct at the calibration points in use but will be inaccurate at intermediate temperatures if the capillary has a fixed diameter at the calibration points but fluctuates between them. The requirement guides the design and usage of liquid-in-glass laboratory thermometers. Mercury-in-glass thermometers are rapidly being replaced with low-cost resistance devices with a digital display or thermally sensitive paint thermometers that provide a clear visual indicator of the temperature. Despite this, liquid-in-glass devices are still plentiful, and their usage will continue owing to easy like-for-like replacement. These devices take use of the thermal expansion differences between various materials, most often metals. When two metal strips are joined together to create a bimetallic strip, the side with the greater coefficient of thermal expansion expands more than the other, causing the assembly to bend.

A mechanical linkage to a pointer with an accuracy of about 61 °C can convert this bending into a temperature measurement. These gadgets have the benefit of not requiring a power source. It is common to utilize them as temperature controls. Thermo couplings are often regarded to as the workhorse of temperature measurement, with several devices capable of measuring temperatures ranging from 2270 to 3000 °C. Because of its cheap cost, simplicity, durability, size, and temperature range, thermocouples are widely utilized [8]. Their sensitivity and speed of reaction are sufficient for many applications, but they are less precise than resistance temperature devices; they need an independent measurement of junction temperature, and extension cables may be costly. The See beck effect lies at the heart of these technologies. In a circuit with two different conductors experiencing a temperature gradient, this produces an electromotive force emf. The emf produced by a thermo element relative to platinum with one junction maintained at 0 °C and the other at a rising temperature is determined by the change of thermo electric power. This table may be used to assist in the choosing of material combinations for thermocouple design. When the objective is to get the highest thermoelectric emf, a thermocouple pair with a large positive and negative emf should be used [9]. The thermocouple materials must, however, be chemically compatible, and there are a variety of alloy combinations to choose from. Noble metal, base metal, high temperature or refractory metal, and nonmetal thermocouples are the four types of thermocouples. Although platinum, for example, oxidizes at 600 degrees Celsius, noble metals are generally inert. Their chemical stability and thermoelectric power make them ideal for thermocouples [10].

## DISCUSSION ON DIFFERENT EQUIPMENT USED FOR MEASURING TEMPERATURE

Certain basic metals, including as copper, iron, nickel, aluminum, and chromium, as well as their alloys with extra impurities, may be utilized to make materials with favorable thermoelectric properties, such as constantan and Chromel, which are especially useful at low and moderate temperatures. Refractory metals such as tungsten, rhenium, certain tungsten and rhenium alloys, and molybdenum may be utilized for higher temperature applications. Tungsten and rhenium have very high melting points (3410 and 3280 °C, respectively), and have been used as thermocouples either alone or in alloys with other materials. These metals oxidize quickly and should not be subjected to oxidizing atmospheres or oxidizing chemicals at high temperatures. Nonmetals like carbon, boron, carbide, and boride compounds are brittle and have poor tensile strength. The use of nonmetals in thermocouples may result in quite large composite rods. The number of thermocouple material combinations available is vast; we listed the properties of over 150 of them. Cost, maximum and lowest working temperatures, chemical stability, material compatibility, atmospheric protection, mechanical limits, length of exposure, sensor lifespan, sensitivity, and output emf are all factors to consider when choosing a thermo couple. Electrical resistance's temperature dependency is critical to the functioning of many devices. Because the mobility of free electrons and atomic lattice vibrations is temperature dependent, a conductor's resistance is linked to its temperature. A resistance temperature device may theoretically be made out of any conductor (RTD).

However, cost, temperature coefficient of resistance a high value leads to a more sensitive instrument, oxidation resistance, and manufacturing limitations limit the options. The most common metals are copper, gold, nickel, platinum, and silver. Copper is a popular choice for temperatures between 2100 and 100 °C since it is reasonably inexpensive. Nickel and its alloys are also very inexpensive, with excellent resistivity’s and temperature coefficients of resistance. The change in electrical resistance with temperature, on the other hand, is nonlinear and strain-sensitive. Platinum has a resistivity six times that of copper, is generally unreactive, and has a well-established temperature coefficient of resistance, making it a popular option for temperatures ranging from 2260 to 962 °C. Germanium, rhodium–iron alloys, and ruthenium oxide have excellent temperature properties, making them ideal for cryogenic applications. Depending on the required precision, a variety of methods for measuring the electrical resistance of an RTD are available, some of which are shown. If a galvanometer is used or the voltage is read, the value of R1 is changed in the fixed bridge circuit until the current flow via the bridge output is zero. R1 equals the unknown resistance under these circumstances, and the temperature may be calculated using a calibration equation. This circuit has errors in its lead wire resistance accounting and should not be utilized for precise readings. In a three-leg RTD circuit, the middle leg's lead resistance is shared by both sides of the bridge. When the bridge is balanced, its resistance cancels off, resulting in a significant reduction in lead wire error. The greatest performance comes from the four-leg design, which eliminates lead wire resistance concerns.

Using a four-wire RTD, which has two leads attached to each end of the sensor, a continuous current source can be connected to two of the leads, and the voltage from the sensor's other two leads can be measured with a DVM. There is minimal loading error from even a 1 kV RTD and insignificant lead-wire resistance errors if the DVM's input impedance is 100 MV or greater. At 0 °C, the output sensitivity of a 100 V PRT supplied with a current of 1 mA is 400 mV/°C. Bridges, potentiometers, and four-wire current/voltage systems may all be powered by ac supply, which allows for simpler amplification and avoidance of spurious dc signals. For example, the inductive ratio bridge is an ac technique that uses precision wound resistors for the ratio arms. A comparison to another thermometer, such as an SPRT may be performed at temperatures between 240 and 250 °C. Depending on the temperature range, in a stirred liquid bath comprising silicone oil, water, or alcohol. Fluidized beds and heat pipe furnaces are better for greater temperatures. If proper processes are followed, the freezing point of water gives a reference temperature with an uncertainty of 0.002 °C. The commercially available water triple point cell, with its reduced uncertainty, is an alternative calibration point that is currently favored. Self-heating, oxidation, corrosion, and strain of the sensor element are all errors that may occur with a PRT. A current must be fed through the gadget to measure the resistance, which may cause local heating. Self-heating mistakes are reduced by reducing current and maintaining excellent thermal contact between the sensor and the surrounding medium. Platinum, while being generally stable, may oxidize at high temperatures. The combined effects of oxidation and thermally induced strain on the overall composition of platinum have been studied. The thermistor is a less expensive type of resistance temperature device than platinum resistance thermometers if precision is not essential. Thermistors are made up of a semiconductor with a temperature-dependent resistance.

Nickel, manganese iron, copper, cobalt, magnesium, titanium, other metals, and doped ceramics are often used in modern thermistors. They're made by sintering particles in a controlled environment. Temperature coefficients in thermometers may be positive or negative. Temperature resistance characteristic of a typical resistance. On 0.01 mm diameter leads, beads as tiny as 0.07 mm in diameter are feasible. These gadgets may be painted, sealed in epoxy resin, or encased in glass. Mixed metal oxides may be used to make stable thermistors at temperatures below 250 degrees Celsius. Refractory metal oxide devices are suitable for temperatures over 300 °C, whereas devices based on zirconia doped with rare earth oxides are suitable for temperatures on the order of 700 °C. Non-stoichiometric iron oxides may be utilized in low-temperature applications. It is possible to utilize an optical fiber to channel heat radiation into a restricted wavelength band from the place of interest to a measuring sensor in order to monitor surface temperatures or gas temperatures, such as in monitoring combustion processes. Optical reflection, scattering, interference, absorption, fluorescence, and thermally produced radiation are all examples of common fiber optic sensors. A cavity constructed at the end of an optical fiber is one commercially available technology. A blackbody emitter is built into the tip of a single crystal sapphire optical cavity that is connected to an optical cable. The cavity closely resembles a blackbody, and the radiant energy is sent to a photodiode or photomultiplier through an optical cable. This device detects the amount of radiation emitted at a certain wavelength and transforms the signal using radiant emission rules. These instruments can detect temperatures ranging from over 100 °C to about 4000 °C. There are many techniques for measuring blackbody radiation, including phosphor tipped fiber optic temperature sensors and interferometric sensors for measuring phase changes between sent and received laser light. The kind of sensor utilized determines the accuracy of these devices. The precision of a sapphire rod device at 1000 °C is claimed to be 1 °C, however the accuracy is restricted by the temperature standard's accuracy. Over a specific temperature range, the electric permittivity of some materials, such as strontium titan ate, may be extremely dependent on temperature.

Encapsulated samples of the material with a capacitance of a few Nano farads and lead wires to a bridge circuit activated at about 100 V may be used to make a viable sensor. Capacitance thermometers have excellent sensitivity below 100 K, but during thermal cycling, the output voltage becomes irreproducible, necessitating calibration against another kind of sensor. Capacitance thermometers, on the other hand, are practically unaffected by magnetic fields. As a result, they're valuable as control devices in strong magnetic fields, when other kinds of devices may fail or generate erroneous signals. Lake Shore Cryotonics Inc. sells commercially available equipment. The random voltage produced by Brownian motion of conduction electrons is the basic concept used in noise thermometry. The technique, which involves measuring the mean square Johnson noise voltage across a resistor, is one of the few viable alternatives to gas thermometry for determining thermodynamic temperature precisely. The equipment needed for this has restricted the method to mainly conventional laboratory applications due to its complexity. This is owing in part to the low noise levels. Also, various kinds of noise must be eliminated or compensated for. Except at very low temperatures, noise thermometry's precision does not equal that of other, typically simpler techniques like the RTD.

Noise thermometry may be used at temperatures ranging from a few mK to over 1500 °C in theory. The kind of circuitry employed depends on the temperature range. Two kinds of absolute noise thermometers have proven effective for low temperature readings of less than 1 K. Both use the SQUID! superconducting quantum interference gadget to detect the noise voltage produced by a resistor. The resistor is inductively linked to the SQUID in one kind. The resistor is linked directly across a Josephson junction two superconductors separated by a thin insulating layer in the other, a resistive SQUID RSQUI an RSQUID device to measure temperatures up to 4.2 K in the 10–50 K range. In certain temperature measuring situations, a temperature sensitive substance may be applied to a surface. The changes in the surface coating's optical characteristics may then be monitored remotely. Because the approach requires alteration of the component of interest and therefore some disruption to the temperature field, these surface coating techniques are classified as semi-invasive. Thermochromics liquid crystals, heat-sensitive crystalline solids and paints, and thermographic phosphors are all examples of heat-sensitive materials. Liquid crystals have shown to be helpful in experimental studies and medicinal applications when the temperature range of relevance is restricted. Liquid crystals have a molecular structure that is halfway between that of a crystalline solid and that of an isotropic liquid. They have certain liquid-like mechanical characteristics as well as crystalline solid-like optical qualities. Liquid crystals, which are optically active and respond to changes in temperature and shear stress via reversible color changes, are particularly relevant to heat transfer investigations. Thermochromics liquid crystals are the common name for these cholesteric crystals. They deteriorate when exposed to ultraviolet UV! radiation and are susceptible to chemical contamination due to their organic composition. Encapsulating the crystals in polymer spheres is a viable solution to this issue that has been embraced by manufacturers.

Commercially available encapsulated thermochromics liquid crystals come in the form of a water-based slurry that may be painted or sprayed with an airbrush on the desired surface. The color of a liquid crystal is determined by a number of factors, including the crystals' orientation, the spectrum character of the light that illuminates the surface, and the spectral response of the sensing device. Nonreversible heat sensitive crystalline solids may be useful for applications that just need an indication of the highest temperature reached. These melt at a certain temperature. They come in a number of commercial forms, including crayons, pellets, and paints, and have been used for decades to indicate temperatures on gas turbine blades and in rocket motors. Instrumentation that is invasive or in touch with the body must be able to withstand the temperature. Invasive instrumentation may deteriorate over time in high-temperature or chemically reactive applications like flames or plasmas; beyond the material limitations, it can dissolve entirely. This restriction does not apply to noninvasive techniques. Furthermore, without the use of telemetry or slip-ring systems, noninvasive instrumentation may be used to determine the temperature of moving components. Temperature readings at a single location as well as the fluctuation across an area may be obtained via scanning. The majority of noninvasive methods use the electromagnetic spectrum to detect temperature. That portion of the spectrum is susceptible to infrared technology. The visible range is dominated by optical methods such as absorption and emission spectroscopy, scattering, and luminescence, owing to the employment of lasers in the system. The measurement of acoustic temperature, which is based on sound speed, is one noteworthy exception. Some optical methods are prohibitively costly because they require the use of a laser, high-quality optics, and specialized data collecting equipment. Temperature measuring devices that utilize thermal radiation in the infrared spectrum to monitor temperatures in the range of 50 to 6000 K are helpful. The source or target, the surroundings, the medium through which the radiant radiation is transferred, typically a gas, and the measuring equipment make up an infrared measurement system. An optical system, a detector, and a control and analysis system may be included in the measuring equipment.

## CONCLUSION AND IMPLICATION

Temperature range, probable maximum temperature, heating rate, responsiveness, precision, stability, sensitivity, ruggedness, service life, safety, environment, and contact techniques are all factors to consider when choosing a method and related equipment for a specific application. The selection of an acceptable method requires a thorough understanding of a broad variety of technologies, as well as what is feasible and what is accessible. The short explanations and references in Sections II–IV are meant to help with this. The selection of appropriate instrumentation may be limited by the application's particular needs. Invasive instrumentation, for example, is prohibited in certain situations. In certain cases, a complete field temperature map is needed; in other cases, point temperature readings may suffice. Accuracy may or may not be worth the expense of purchasing the necessary equipment. Table V provides information based on a variety of typical selection criteria that may be utilized to aid in the initial selection of an acceptable method.

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