iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IV **Month of publication:** April 2021

DOI: https://doi.org/10.22214/ijraset.2021.33800

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

Contact and Non-Contact Temperature Acquisition Sensors: A Review

Irene Jijo[1], Sandy Jose Panicker[2], Isen Mathew Ben[3], K. G. Satheeshkumar[4]
[1, 2, 3, 4]Department of Electronics and Communication, Amal Jyothi College of Engineering, Kottayam, India

Abstract: Reliable and accurate measurement of temperature is a crucial step in many sciences. There exist multiple methods to obtain a target's temperature which involve either direct contact or through indirect methods. We sift through different methods of temperature measurement to find a method that can reliably give us the measurement with lowest error and suit a wide range of applications. This requirement is to an extent satisfied by radiation pyrometry which comes under non-contact temperature sensor. This can used in applications ranging from human body temperature measurement to industrial temperature acquisition applications.

Keywords: Temperature sensors, Contact and Non-Contact Temperature Sensors Pyrometers, IR Pyrometers

I. INTRODUCTION

Any object whose molecules are not at rest is said to contain heat and will be above absolute zero. In other words, the heat of an object is the sum total of the molecular motion inside the said object. Temperature is an expression of the object's thermal energy or the average of the heat contained in its molecules.

Temperature, an extension of heat defines the state of matter, plays a role in the molecular composition of a compound, provides and insight into the internal state of a material and provides an indicator regarding the wellness of an organism. This makes accurate measurement of temperature a matter of high priority.

Every object above absolute zero emits energy through its surface and we have a plethora of methods to measure this energy and calculate the temperature. We measure the energy emitted from the surface and we call that a contact temperature measurement while measurement of the energy radiated from the surface at a distance from the said object is called non-contact temperature measurement.

Both methods yield us the temperature and they have their domains where they are a necessity but if we were to design a sensor that can be utilised in a wide range of applications where, contact and non-contact thermometers have their own niche segments then, it becomes necessary to look through available methods to find best suitable method of temperature acquisition.

II. CONTACT TEMPERATURE SENSORS

Calculating or measuring the temperature from the energy emitted by a body from its surface forms the core of contact temperature sensors. A probe of sorts in inserted/lowered or made to touch with our target of interest. Upon contact with the target body the probe undergoes a change which corresponds to the amount of energy transferred from the target body to the probe. The nature of the change depends on the composition and configuration of the probe. High precision and fast response are the main advantage [1]. Along with these advantages they provide accurate readings, maintenance is very less, cost is less. They provide low clearance and high reliability [2].

Hence contact temperature sensors are of the following types (we have considered only sensors whose output is electrical in nature):

A. Thermocouples

Thermocouples have a low heat capacity therefore has a faster response. Thermocouples thus are most commonly used to get quick measurements in shorter intervals. They are directly used to measure human body temperature. It has two ends: one hot another cold. Hot end directly gets in contact with human body whereas other end is the reference end. EMF difference between ends can give us an idea of the temperature. In most applications cold end temperature is constant or 0ºC [1]. It is made of two wires of different metals, joined together at end to form a junction with the output in millivolts. Usually comes with hand held temperature probe or multi-meter. They are quick and very easy to use. Most common type is K – Nickel Chromium and Nickel Chromium Aluminium. They are also known as separated junction method. They are mainly used to measure temperature of metallic surfaces. Different metals are linked together to identify the difference in voltage. If we are linking same metals then there won't be any changes. The working of thermocouples depends on an effect called Seebeck Effect.

The Seebeck effect refers to the development of an electromotive force when there is a temperature difference between metals. As the temperature difference increases Seebeck EMF increases current flow occurs [3]. Thermocouples are also affected by the changes in temperature that can reduce the accuracy in temperature measurement [4]. Thermocouples measures temperature between −200 to 350 °C range. [1]. On comparing to other methods thermocouples have low stability and less sensitivity.

B. Resistance Temperature Detectors (RTDs)

RTD's are more accurate compared to thermocouples because the metal used is platinum which is much more stable. Sensing elements made up of metals are used in Resistance Temperature Detector. RTD's are formed using coil made of metal. In RTD'S resistance increases along with the increase in temperature as predicted by Ohm's law. Platinum is mostly commonly used since it is accurate, reliable, stable material [5]. Range of temperature is approximately between −200°C to + 850°C. It has four leads, two of them are connected to opposite arms of the bridge circuit and other two leads are connected to the opposite arms of the bridge. Two wires carry the excitations and other two measure the voltage across the sensor. To find resistance a bridge balance technique is being used. Unbalanced output is balanced by converting it in terms of unknown temperature [6]. RTD's provide stable result for long period. They are expensive while comparing with thermocouples therefore are not used in modern medical field [7]. They are commonly used in Aerospace, Analytical Equipment, Food Service Equipment, Semiconductor Equipment, Food & Beverage Processing. Temperature sensing range is between -260 ºC to 850 ºC. A drawback is that electric current should not exceed the threshold and over-heating should be prevented as they can cause erroneous results.

C. Thermistors

They strongly depend upon the temperature more than resistance also known as thermally resistive device. In this case, resistance changes non-linearly with temperature while RTD's changes linearly with temperature [8]. Temperature of thermistors and skin are considered as same thus thermistors are a perfect option for people who require continuous temperature monitoring. When human body temperature ranges between 25 °C and 45 °C then the resistance is between 980 Ω to about 2250Ω [9]. Thermistors are classified into NTC or Negative Temperature Coefficient thermistors, and PTC or Positive Temperature Coefficient thermistors depending upon the slope of temperature-resistance curve. For industrial use characteristics should remain constant during use and be maintained, along with permanent contact. They are known as fast responding thermometers. NTC thermistor materials are formed using solid-state reaction techniques. If semiconductors can conduct electrons, then thermistor is stable and is not sensitive to impurities [8]. PTC thermistor uses stable ceramics for higher performance using higher purity raw materials, keeping high purity throughout the fabrication processes and exact control of the firing process are necessities in technological aspects [10]. NTC thermistors are used for high-precision temperature measurements. Thermistor calibration system is estimated as 4.31mK as the combined standard uncertainty. They are smaller, faster response, less sensitive to shock or vibrations [11]. Temperature sensing range lies between -80 ºC to150 ºC. It has a very narrow sensing region compared to thermocouples and RTDs while possessing an accuracy around 1 ºC.

D. Semiconductor based Temperature Sensors

They are a special category of low temperature sensors which utilize semiconductors, in this case Germanium to act as the temperature sensor. It possesses a small sensing range from -243.15 ºC to 26.85 ºC and depend on the very sensitive dependence of semiconductors on temperature regarding its current-voltage relationship. It is a very device with a compact design suitable for portable applications. It has an accuracy of 0.5K and is very stable due to the operational amplifiers used in its design. The only drawback is the narrow sensing range [12].

III.NON-CONTACT TEMPERATURE SENSORS

The target body emits energy in form of electromagnetic waves which are analysed and temperature determined forms the basis of non-contact temperature sensors. These sensors are vital when it comes to the measurement of objects which either cannot come into contact due to distance or its speed of motion or the nature of the target where either the temperature changes due to contact or a property due to which being into contact is not preferred, an example being a furnace where it is not practical to place contact probes [13]. This form of temperature measurement is commonly referred to as pyrometry. The technique may utilise visible wavelengths or those of longer wavelengths such as infrared waves.

Pyrometry depends on the electromagnetic waves emitted by objects above absolute zero and Plank's radiation law connects the temperature of the target in question with its spectral radiance.

$$L(\omega, T) = \frac{E(\omega, T)\, c_1}{\omega^5 \left[e^{c_2/\omega T} - 1\right]}$$

Fig. 1 Plank's Law of Radiation

L (ω, T) is the spectral radiance as a function of wavelength ω and absolute temperature T. c_1 = 3.7413 × 10 − 12 W · cm2 and c_2 = 1.4388 cm · degree are– the first and second radiance constants, and E (ω, T) is the spectral emissivity of the surface, which also is a function of temperature. For a perfect blackbody this becomes 1 [14].

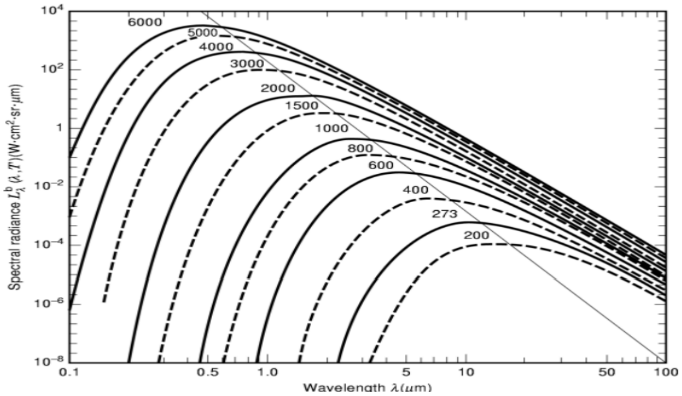


Fig. 2 Planck curves (curves are for constant blackbody temperature, in K)

The curves given by the Plank's law of radiation for different blackbody temperature suggest that the radiance peaks shift to longer wavelengths as the temperature decreases. Therefore, we have two types of pyrometry, Optical pyrometry for higher temperature targets emitting radiation in visible range and Radiation pyrometry can be applied to the entire spectrum regardless of the wavelength.

A. Optical Pyrometry

Objects that emit electromagnetic waves in visible spectrum are the targets of Optical pyrometry, where the emitted radiation is in visible range and the temperature are high. They are much needed in furnaces and its like where one deals in high temperature bodies. The main working principle depends on comparing the brightness of the object being investigated to a reference light source whose temperature is known. While we use the visible spectrum, we only utilise only a portion of it. That is, we use a monochromatic source to make the comparison for accuracy of readings. Furthermore, the Optical pyrometry is divided based on method of introducing the comparison source or on how we compare the two sources [15]. The most commonly used type is the disappearing filament type optical pyrometer.

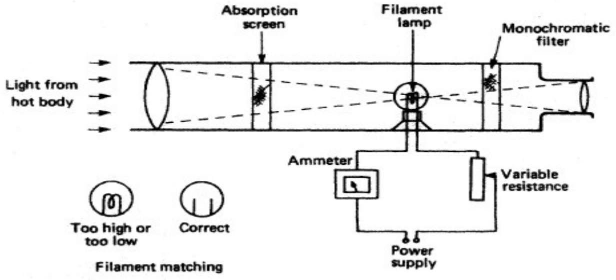


Fig. 3 Disappearing Filament Optical Pyrometer

The radiation from the source being investigated enters the pyrometer through the absorption screen and at its focal point sits an incandescent filament whose brightness is controlled by its driver circuit. The radiation then passes through a monochromatic filter into the eyepiece. The filament is the comparison source in this pyrometer. The filament appears dark in contrast to the target brightness is the filament brightness is below the target brightness and the filament is appears brighter than the incoming radiation if it is brighter than the target.

Only when both the sources are of equal brightness the filament will disappear. Using this information, the temperature of the target can be calculated with the current and voltage measurements of the filament when both the filament and the target was at same level of brightness [16].

When discussing the accuracy of Optical pyrometry in general we find that the standard deviation is about 1°C at 800 °C to 2 °C at 2200 °C and 10 °C at 4000 °C. The commercial variants have a much larger degree of deviation and this deviation needs special methods to reduce it. This can be understood as that temperatures below 800 °C will be accurately measured but when temperatures reach above this point deviation starts to occur which reduces the accuracy of measurements [17]. Its range of applications include measurement of Induction heating, crystal growth, furnace control, glass manufacturing and measurement of liquid metals.

B. Radiation Pyrometry

The Optical pyrometry is accurate till 800 °C but begins to express deviations as temperature goes higher. This is because the optical pyrometry is done using one or two wavelengths and requires the knowledge of the target body's emissivity. Emissivity is a property of an object that determines how much radiation it will radiate or be able to. For a perfect blackbody the emissivity is 1 with all the others ranging [0, 1). Emissivity is a function of wavelength and temperature and it can only be measured experimentally thus needing us to find the temperature to determine the emissivity. This implies that optical pyrometry can he useful in cases where we have the emission spectra of the target. It is extremely arduous or sometimes impossible to study the emission spectra of all the elements such as multicomponent compounds, thin layer materials, composite material and so on. To limit the uncertainties due to lack of emissivity data we utilize the pyrometry data taken in various wavelengths. This makes the entire process much tedious and better methods have be sought after.

This led to improvements in Spectral pyrometry where instead of using the emissivity, the target body is approximated as a grey-body and the temperature calculated as a function of radiation-intensity distribution [18]. The radiation emitted by the body under investigation is measured in different channels with different spectral features and can be analysed using varying channel widths and different wavelengths. This is the basis of multi spectral pyrometry. While this sounds to be a better option, there have not yet been a consensus on the best multi-spectral configuration for the most accurate temperature measurements as various other uncertainties such as background radiation and target temperature fluctuation decrease the reliability of the technique [19]. As multi-spectral pyrometry is still not free from the emissivity dependence, a new technique to calculate emissivity using the body's reflectance has been found. Reflectance is defined and the ratio of radiant flux reflected to incident radiant flux or in other words, how effective a material is in reflecting incident radiant energy. Utilising this technique gives us a temperature measurement of 0.5 °C but the accuracy decreases when there is significant amount of scattering or when the absorption is large [20].

This leads us to a variant of radiation pyrometers known as Infrared (IR) pyrometers which has a temperature sensing range of -50 °C to 3,500 °C. This pyrometer utilises waves in the infrared range to calculate the temperature of our target body and its working is governed by Stefan-Boltzmann's fourth power law.

$$L = \frac{\sigma}{\pi} T^4 \qquad\qquad E = \sigma \cdot \epsilon \cdot T^4$$

Fig. 4 Stefan- Boltzmann fourth power law

The L stands for the spectral radiance, σ is the Stefan-Boltzmann constant, ε is the emissivity of the object, T stands for absolute temperature and E represents total radiant energy. The IR pyrometer shows a great deal of accuracy and reliability needed for industrial and medical applications as the deviation from actual temperature to that measured by the IR pyrometer is ±0.5 °C [21].

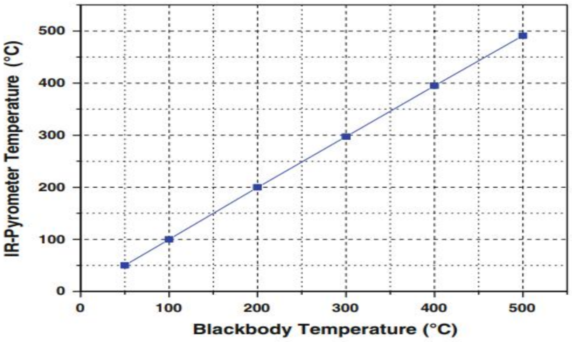


Fig. 5 Curve between the blackbody temperature and that measured

Due to its high accuracy and reliability IR pyrometry can be reliably used in Non-Destructive testing and is able to detect defects in materials in an industrial application. The IR pyrometry shows a strong SNR with the ability to be used in automation [22]. We see application in field of medical sciences where patients need continuous monitoring, IR pyrometry comes in handy as the temperature modules can be made compact and as non-intrusive as possible allowing development of wearable devices. This technology can be made the basis of IR thermography allowing us to scan materials such as food and detect foreign bodies allowing better quality control. This can be used in ships and mobile marine systems to detect quality of sea water and check for leakage of hazardous materials [23].

Table I Comparison of All Mentioned Sensors

SENSORS	Contact Temperature Sensors				Non-Contact Temperature Sensors		
	Thermocouples	RTD	Thermistors	Semiconductor based Sensors	Optical Pyrometers	Spectral Pyrometers	IR Pyrometers
SENSING RANGE	78K – 623K	13K – 1123K	193K – 423K	30K – 300K	973K – 4273K	800K – 140kK	223K – 3773K
DRAWBACKS	Susceptible to electrical interference	Slow response	Fragile in nature	Internal dissipation can affect measurement	Target should emit radiation in visible range	Background radiation and insufficient emissivity data adversely affects operation	Affected by proximity to a radio frequency with an electromagnetic field strength of three volts per meter or greater

IV. CONCLUSIONS

Temperature is a very important parameter in many applications ranging from industrial to home appliances. Determining a temperature sensor that can be used as a general sensor is difficult as all sensors possess their own drawbacks. Hence on comparison we found that IR Temperature sensors are the ones that come close to being a general-purpose sensor as it has a wide temperature range and can be made into compact designs for portability. They fulfil their roles from industrial applications to medical fields in obtaining human body temperatures. There is scope for further development in IR temperature sensors as they have a huge potential due to their versatility.

REFERENCES

[1] Guojing Wang, Weidong Wang, Kaiyuan Li, Hongyun Liu, “A Digital Thermometer With Fast Response and High Precision”, 7th International Conference on BioMedical Engineering and Informatics ,2014

[2] J. Xu et al., "Contact/Clearance Sensor for HDI Subnanometer Regime," in IEEE Transactions on Magnetics, vol. 50, no. 3, pp. 114-118, March 2014, Art no. 3300205, doi: 10.1109/TMAG.2013.2286619.

[3] Thomas J. Bajzek. “Thermocouples: A Sensor for Measuring Temperature”, IEEE Instrumentation & Measurement Magazine, March 2005

[4] A. BALLANTYNE and J. B. MOSS. “Fine Wire Thermocouple Measurements of Fluctuating Temperature”, Combustion Science and Technology 1977, Vol. 17, pp. 63-72

[5] Thomas W. Kerlin, Belle R. Upadhyaya,: Modern Component Families and Circuit Block Design, 2000

[6] S.K. Sen a, T.K. Pan b, P. Ghosal c, “An improved lead wire compensation technique for conventional four wire resistance temperature detectors (RTDs)”, Measurement 44 (2011) 842–846

[7] Becky Crossley; Troubleshoot It: Accuracy of Various Thermometer Types Is Important to Consider During the COVID-19 Pandemic. Biomed Instrum Technol 1 May 2020; 54 (3): 228–229. doi: https://doi.org/10.2345/0899-8205-54.3.228

[8] [8] J. A. Becker, C. B. Green and G. L. Pearson, "Properties and uses of thermistors — Thermally sensitive resistors," in Electrical Engineering, vol. 65, no. 11, pp. 711-725, Nov. 1946, doi: 10.1109/EE.1946.6439939

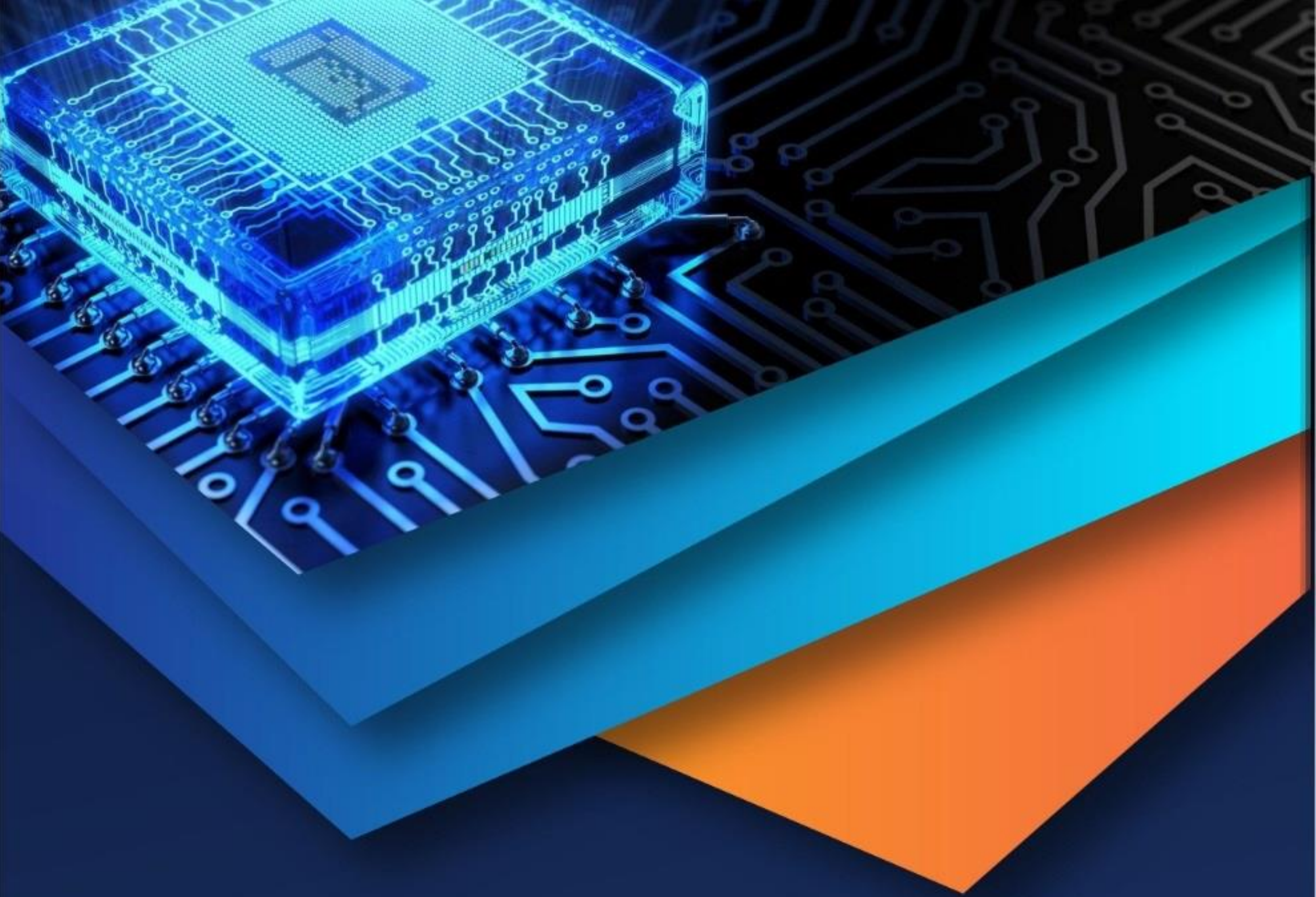
[9] P. Narczyk, K. Siwiec and W. A. Pleskacz, "Precision human body temperature measurement based on thermistor sensor," 2016 IEEE 19th International Symposium on Design and Diagnostics of Electronic Circuits & Systems (DDECS), Kosice, Slovakia, 2016, pp. 1-5, doi: 10.1109/DDECS.2016.7482451

[10] H. Ueoka and M. Yodogawa, "Ceramic Manufacturing Technology for the High-Performance PTC Thermistor," in IEEE Transactions on Manufacturing Technology, vol. 3, no. 2, pp. 77-82, December 1974, doi: 10.1109/TMFT.1974.1135679

[11] Guang Liu, Liang Guo, Chunlong Liu, Qingwen Wu, “Evaluation of different calibration equations for NTC thermistor applied to high-precision temperature measurement”, Measurement, Volume 120, 2018

[12] Huen, T. (1970). Semiconductor Diode Low Temperature Thermometer. Review of Scientific Instruments, 41(9), 1368–1369. doi:10.1063/1.1684826

[13] Khan, M. A., Allemand, C., & Eagar, T. W. (1991). Noncontact temperature measurement. I. Interpolation based techniques. Review of Scientific Instruments, 62(2), 392–402. doi:10.1063/1.1142133
[14] Stein, A. (1999). Pyrometers. Wiley Encyclopedia of Electrical and Electronics Engineering. doi:10.1002/047134608x.w3939
[15] Forsythe, W. E. (1925). Optical Pyrometers*. Journal of the Optical Society of America, 10(1), 19. doi:10.1364/josa.10.000019
[16] Lovejoy, D. R. (1959). Photometry of the Optical Pyrometer and Its Use below 800°C. Journal of the Optical Society of America, 49(3), 249. doi:10.1364/josa.49.000249
[17] Lovejoy, D. R. (1958). ACCURACY OF OPTICAL PYROMETRY IN THE RANGE 800 °C TO 4000 °C. Canadian Journal of Physics, 36(10), 1397–1408. doi:10.1139/p58-140
[18] Magunov, A. N. (2009). Spectral pyrometry (Review). Instruments and Experimental Techniques, 52(4), 451–472. doi:10.1134/s0020441209040010
[19] Araújo, A. (2017). Multi-spectral pyrometry—a review. Measurement Science and Technology, 28(8), 082002. doi:10.1088/1361-6501/aa7b4b
[20] Gardner, J. L., & Jones, T. P. (1980). Multi-wavelength radiation pyrometry where reflectance is measured to estimate emissivity. Journal of Physics E: Scientific Instruments, 13(3), 306–310. doi:10.1088/0022-3735/13/3/016
[21] Rani, A., Upadhyay, R. S., & Singh, Y. P. (2013). Investigating Temperature Distribution of Two Different Types of Blackbody Sources Using Infrared Pyrometry Techniques. MAPAN, 28(2), 91–98. doi:10.1007/s12647-013-0046-0
[22] Usamentiaga, R., Venegas, P., Guerediaga, J., Vega, L., Molleda, J., & Bulnes, F. (2014). Infrared Thermography for Temperature Measurement and Non-Destructive Testing. Sensors, 14(7), 12305–12348. doi:10.3390/s140712305
[23] Bagavathiappan, S., Lahiri, B. B., Saravanan, T., Philip, J., & Jayakumar, T. (2013). Infrared thermography for condition monitoring – A review. Infrared Physics & Technology, 60, 35–55. doi:10.1016/j.infrared.2013.03.006



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