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Metal Temperature Measurement Technologies

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Abstract*: Discovery of Metals was one of the greatest achievements for humans. From the discovery to until now metals are used in almost every industry, we are surrounded by a metallic world. Metal temperature measurement is an integral part of many industrial operations. Accurate temperature measurement is very important for safety, process efficiency and product quality. Depending on the specific application and desired temperature, the industry uses many technologies to control metal temperature. In many industrial operations, including metal forming, heat treatment, and welding, accurate and consistent metal temperature measurement is crucial. An overview of the numerous temperature sensors used in industry and the most current developments in metal temperature measuring technology are provided in this review paper*

Keywords: Temperature measurement, thermocouples, contact temperature sensors, non-contact temperature sensors, industry

I. INTRODUCTION

Metals are affected by temperature changes, changing temperatures cause dimensional changes in metals and alloys, which have important consequences for companies that process these materials at high temperatures. In many industrial operations, including metal forming, heat treating and welding, metal temperature control is critical. Accurate and reliable temperature measurements can ensure product quality, increase process efficiency and improve operational safety.

Contact and non-contact temperature sensors are the two main types used in industry. Contact sensors directly touch a metal surface to measure its temperature, such as thermocouples and resistance temperature detectors (RTDs). Infrared pyrometers are non-contact sensors that estimate the temperature of a metal surface by detecting the infrared radiation it emits. Selecting the temperature depends on certain factors such as temperature range to be measured, required accuracy, the environment in which the sensor is to be used and also on the cost of the sensor.

Among the contact and non contact sensors, contact sensors can be more difficult to install and maintain, they are often more accurate than non-contact sensors. Non-contact sensors are easier to install and update, but can be less accurate, especially if the metal surface is corroded or dirty.[11]

New materials and designs for more precise, dependable, and long-lasting sensors have been developed as a result of recent advancements in metal temperature measuring technology. For instance, novel sensor materials that are more resistant to extreme heat and severe chemicals have been created. Additionally, new, more convenient to install sensor versions have been created that are small.

Measurement of metal temperatures is essential to many industrial operations. Manufacturers may increase product quality, process effectiveness, and operational safety by precisely monitoring and detecting metal temperature. Recent developments in metal temperature measuring have made it possible to monitor metal temperature in even more difficult settings with greater accuracy and dependability.

II. LITERATURE OVERVIEW

Thermocouple arrays are emerging as powerful tools for precise temperature monitoring in welding applications. Unlike traditional single-point sensors, they offer high spatial resolution, capturing nuanced temperature variations across the weld zone. This real-time insight allows for proactive process control and defect detection, potentially leading to improved weld quality and reduced rework. A case study on submerged arc welding demonstrates the effectiveness of arrays in mapping temperature gradients and identifying potential flaws. While careful consideration is needed for material selection and data analysis, the research suggests that thermocouple arrays hold significant potential for revolutionizing welding by enhancing quality, efficiency, and cost-effectiveness. Further research on tailoring their use for specific welding applications is encouraged to fully unlock their potential.[1]

Research proposes a novel infrared computer vision method for accurately measuring and compensating the temperature of molten iron in blast furnaces. Traditionally, thermocouples have been used, but they suffer from limitations like contact contamination and short lifespans. This method, utilizing infrared cameras and image processing algorithms, addresses these issues by offering non-contact, real-time temperature measurement across the entire molten iron surface. The study demonstrates the effectiveness of the method through simulations and experimental validation, achieving high accuracy compared to traditional thermocouples. Additionally, the proposed compensation algorithm adjusts for potential emissivity variations, further enhancing the temperature measurement accuracy. Overall, this infrared computer vision technique presents a promising alternative for monitoring blast furnace molten iron temperature, potentially leading to improved process control, energy efficiency, and iron quality.[2]

The paper "Integration of Thermocouple-Based Sensors into 3-D ICs" delves into the challenges, solutions, and design methodology associated with integrating thermal sensor technology into 3-D integrated circuits. It tackles the significant hurdles in thermal management in 3-D ICs and proposes a distinctive approach utilizing bimetallic thin-film thermocouples and dedicated vias for thermal sensing. The study presents a streamlined design methodology and a comprehensive system for implementing the sensor network and its analog interface circuitry. Additionally, it explores the tradeoffs and considerations of repurposing thermal through-silicon via (TSV) resources for temperature sensing infrastructure in 3-D ICs. Ultimately, the research contributes to the progression of thermal management techniques in 3-D integrated circuits, providing valuable insights for professionals and researchers in the semiconductor technology and integrated circuit design domain.[3]

There are seven key temperature measurement technologies for factories of the future, emphasizing the importance of accurate temperature measurement for ensuring product and equipment integrity. Each technology is suited for a specific range of temperatures, and the authors discuss research priorities for both individual technologies and temperature measurement in general.[4]

Study investigates the measurement of temperature distribution in metal cutting processes to enhance machining operations. By employing both a K-type thermocouple and an infrared radiation pyrometer, the tool temperature and tool-chip interface temperature were estimated during orthogonal metal cutting. The results revealed that increasing cutting speed, feed rate, and depth of cut led to higher tool temperatures, with cutting speed being the most influential parameter. The heat distribution data provided valuable insights for optimizing cutting parameters. The findings underscore the significance of accurately determining the relationship between cutting parameters and heat distribution in metal cutting processes, offering potential improvements for machining operations.[5]

Flexible, measurement-assisted assembly technology has become increasingly important in the manufacturing of aircraft. This technology offers numerous benefits, including increased efficiency, reduced costs, and improved quality. Digital flexible assembly fixtures, advanced automation connection devices, and digital metrology systems are some of the key technologies used in this field. The use of these technologies can significantly improve the assembly quality and efficiency of aircraft. In addition, the future development trend of flexible assembly fixtures is focused on cost reduction. The integration of flexible assembly systems with commercialized industrial robots can also help reduce fixture costs. Overall, flexible, measurement-assisted assembly technology represents the developing direction of the current aircraft manufacturing industry.[6]

In the race towards smarter factories, temperature management takes center stage. This review investigates seven key temperature measurement technologies, assessing their potential for precise monitoring and control in industrial settings. Each technology is evaluated for its compatibility with different temperature ranges and its suitability for diverse factory applications. Recognizing the field's ongoing evolution, the authors call for further research in refining accuracy, miniaturization, and real-time data analysis capabilities of these technologies. By prioritizing these advancements, thermal characterization within the factories of the future can reach new heights.[7]

Thermocouples, workhorses of the temperature sensing world, rely on a simple yet powerful trick: heating two different metals joined together creates a tiny voltage. This voltage tells us how hot it is. Their ruggedness and wide temperature range make them perfect for tough jobs like monitoring furnaces or airplane engines, but even they have limits. Luckily, research keeps pushing their accuracy and shrinking their size, making them even more vital for building the smarter factories of tomorrow.[8]

In the fiery heart of molten metals, measuring temperature is no easy feat. Wakeham and Peralta Martinez take us on a captivating journey, revealing how scorching heat, swirling flows, and even the metals themselves play tricks on traditional thermometers. But they don't leave us in the dark! They shine a light on promising new approaches, from clever sensor designs to smart data processing, opening the door to revolutionizing how we handle these mysterious yet crucial materials.[9]

Accurately gauging the expansion of metals and alloys amidst scorching temperatures poses a formidable challenge in materials science. James et al. dive into this crucial topic, meticulously reviewing established measurement techniques like dilatometry and optical methods. Their analysis dissects the strengths and limitations of each approach, highlighting their suitability for different materials and temperature ranges. Recognizing the ever-evolving landscape, they champion the exploration of promising new methods like electrical pulse heating and X-ray diffraction, paving the way for future advancements in characterizing thermal expansion at high temperatures.[10]

A variety of techniques are available enabling both invasive measurement, where the monitoring device is installed in the medium of interest, and non-invasive measurement where the monitoring system observes the medium of interest remotely.[11]

There are different effects and properties related to thermocouples like seebeck effect, peltier effect etc. in the field of thermoelectricity.[12]

In machining, accurately measuring temperature at the tool-work interface is crucial for optimizing processes and minimizing tool wear. While challenging due to high pressures and rapid temperature fluctuations, thermocouples offer advantages like small size and fast response. Stephenson's paper tackles implementation issues like optimal sensor placement, protecting the thermocouple from damage, dealing with signal interference, and interpreting data considering heat transfer within the tool and workpiece. Though challenges remain, understanding these factors enhances the potential of thermocouples for optimizing and controlling machining processes.[13]

III. KEY TEMPERATURE MEASUREMENT TECHNOLOGIES

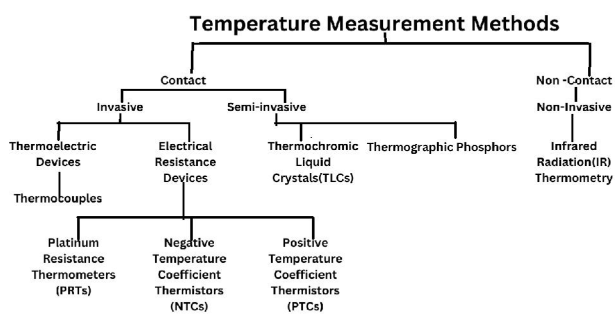

Fig 1. Classification of various temperature measurement techniques.

The fig1. shown above gives the classification of all the techniques used for measuring the temperature.

Contact Temperature Measurement: In Contact Temperature measurement the sensor and the object are in direct contact. The sensor measures the temperature by conduction.[11]

Invasive: The invasive sensors are in direct contact with the object. It involves direct placing of the sensor with the object whose temperature is required to be measured. It can damage or alter the object. These types of sensors are the most accurate for temperature measurement. [4][8]

Thermoelectric Devices

- Thermocouples: A sensor used to monitor temperature is called a thermocouple. It is made up of two different electrical conductors that are joined at one end. A voltage is formed between the two free ends of a junction of two metals when the connection is subjected to a temperature differential. The temperature difference between the hot and cold junctions is inversely correlated with this voltage.[8][4]

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- Electrical Resistance Devices: Temperature sensors known as electrical resistance devices (ERDs)[4] depend on the correlation between a material's electrical resistance and temperature. As the temperature varies, the material's resistance alters. The temperature of the material may be determined using this change in resistance.
- Platinum Resistance Thermometers(PRTs): The most precise and reliable ERDs are platinum resistance thermometers (PRTs). Platinum, which has a very linear relationship between resistance and temperature, is the material used to make PRTs. In applications requiring great precision, such calibration labs and research, PRT devices are used.
- Negative Temperature Coefficient Thermistors(NTCs): NTCs are semiconductor devices. Their resistance decreases as the temperature increases. So they are less accurate than PRTs but faster. NTCs are used where higher response time is required.
- Positive Temperature Coefficient Thermistors(PTCs): PTC thermistors are semiconductors with positive temperature coefficients, meaning that their resistance rises with temperature. Resistance and temperature have a very nonlinear connection in PTCs. As a result, they are less precise than PRTs, but they are also far more sensitive to slight temperature fluctuations. PTCs are frequently utilized in applications like power supply and motor windings where over temperature safety is necessary.
- Semi-Invasive: In the[4] Semi-Invasive method the sensor and object should be in contact , but not need to penetrate the object's surface. This method reduces chances of damage to the object. This method is used in medical applications, and also in industrial applications.
- Thermochromic Liquid Crystals(TLCs): TLCs are the materials which change their color when there is a temperature change. TLCs have molecules and they are aligned in a specific manner. When there is a temperature change the alignment of molecules changes which changes the reflection of light from material so this change results in the color change.
- Thermographic Phosphors: The materials which emit light when they are heated are Thermographic phosphors. These consist of inorganic molecules which are doped with impurities The temperature of Phosphors is proportional to intensity light emitted. It is used in Temperature measurement, thermal imaging, non-destructive testing, medical imaging, security screening.
- Non-Contact Temperature Measurement: In this technique the temperature of the object is measured from a particular distance i.e no direct contact is involved here.[8]
- Non-Invasive: In the Non-Invasive technique there is no direct contact between the sensor and object. For example, a thermal imaging camera doesn't have any contact with the object. The accuracy of these types of sensors is less but at the same time they are less damage prone
- Infrared Radiation (IR) Thermometry: It is a non-contact technique of temperature measurement. It uses the relationship between infrared emitted by the object and its temperature.[9] Almost every object emits infrared radiation and the intensity of radiation is directly proportional to the temperature of the object.[5][11]

How does it work?

It focuses the infrared radiation emitted by an object on a detector. Then the detector converts the radiation into the form of an electrical signal, then the electrical signal is amplified and processed to determine the temperature of the object.

Its advantages are non-contact, fast response time, wide temperature range and its safety. And some disadvantages are accuracy, distance, emissivity, ambient temperature these advantages are due distance between object sensors.

Table 1. Comparison of temperature measurement techniques.

Features	Contact measurement techniques	Non-contact measurement techniques
Contact Required	Yes	No
Accuracy	Comparatively more accurate	Comparatively less accurate

Response Time	Generally slower	Generally fast
Temperature range	Limited by material of sensor	limited by type of sensor
Emissivity dependence	Not affected	It is affected by emissivity of object to be measured
Cost	Less expensive	Generally more expensive
Applications	Furnaces, ovens, kilns, boilers, engines, turbines	Moving objects, objects that are difficult or impossible to reach, objects that must not be contaminated

The table above gives the general comparison of the contact and non-contact temperature measurement techniques. The comparison is done for a better overview about the topic discussed in the review paper.

IV. UNDERSTANDING THERMOCOUPLES

How Thermocouples work?

Thermocouples work on the principle of seebeck effect. It works as when two dissimilar metals are joined together to each other , a voltage is developed at the junction point when there is a difference in junction and other end of the metal. The temperature difference and magnitude of voltage are directly proportional to each other.[1][8]

The voltage generated by thermocouples is given by[3]:

$$V = \alpha(T1 - T2)$$

where,

V is voltage generated by the thermocouple

T1 is the junction temperature

T2 is temperature of other end of the metal

α is the coefficient seebeck coefficient

Each combination of thermocouple materials has a particular material characteristic called the Seebeck coefficient. Typically, the Seebeck coefficient is stated in microvolts per degree Celsius (V/°C).

Types of Thermocouples:

There are various types of thermocouples available there and some of them are,

1. J Type(iron-constantan): It is a general purpose thermocouple and its range from -40 to 750°C.
2. K Type(chromel-alumel):It is a general purpose thermocouple and its range from -200 to 1260°C
3. S Type(platinum-10% rhodium/platinum): This is a high temperature range thermocouple with range of 0 to 1600°C.
4. T Type(copper-constantan): It is low temperature thermocouple and its range is -200 to 400°C
5. E Type(chromel-constantan): E type is High temperature thermocouple with a range of 0 to 1000°C.
6. R Type(platinum-13% rhodium/platinum): R Type is also a High temperature thermocouple with a range of 0 to 1600°C.
7. Type B (platinum-30% rhodium/platinum-6% rhodium): B Type thermocouple is a High temperature thermocouple with a range of 0 to 1800°C.
8. Type C (tungsten-5% rhenium/tungsten-26% rhenium): C Type thermocouple is a High temperature thermocouple with a range of 0 to 2320°C
9. Type D (tungsten-3% rhenium/tungsten-25% rhenium): D Type Thermocouple is a High temperature thermocouple with a range of 0 to 2320°C.

Selection of Thermocouple: There are a number of factors which are considered for selection of thermocouple

- Temperature Range
- Required Accuracy
- Environment required for thermocouple use
- Cost

Calibration of thermocouple is an important process for accurate temperature measurement. Calibration process involves comparing the readings of thermocouple temperature to a known temperature standard.

V. CONCLUSION

From the various temperature measurement techniques for metal , like Contact and Non-Contact it concludes that contact sensors are more accurate than the non-contact sensors but contact sensors may damage the object due to direct insertion, But for greater accuracy Contact sensors are more preferred.

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