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Application of K-Type Heated Junction Thermocouples for Water Level Measurement in PWR and BWR Reactors: A Comparative Study of 2-Wire vs. 3-Wire Connections

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Abstract: Accurate water level measurement in nuclear reactors, particularly in PWRs (pressurized water reactors) and BWRs (boiling water reactors), is essential for ensuring the safety and efficiency of reactor operations. K-type HJTCs (heated junction thermocouples) are widely used for this purpose due to their ability to withstand extreme temperatures and radiation conditions. This article explores the role of HJTCs in reactor water level measurement and compares the performance of 2-wire and 3-wire connections. While the 2-wire connection is simple and cost-effective, it can introduce measurement inaccuracies due to wire resistance. In contrast, the 3-wire connection compensates for lead resistance, offering more precise and reliable measurements, particularly in long-distance applications. This paper discusses the operational considerations of these wiring configurations in the context of nuclear reactors and highlights the importance of choosing the appropriate connection type to optimize safety and measurement accuracy in PWR and BWR reactors.

Key words: K-type thermocouple, heated junction, water level measurement, PWR, BWR, temperature measurement, nuclear reactor instrumentation, thermocouple wiring configurations, 2-wire vs. 3-wire connection, radiation resistance.

1. Introduction

To start with, HJTCs (heated junction thermocouples) (Fig. 1) play a crucial role in nuclear reactors like PWRs (pressurized water reactors) and BWRs (boiling water reactors) for monitoring water levels, ensuring operational safety, and preventing accidents from PRA (probability risk analysis) point of view and perspective in particular in SMRs (small modular reactors) [1-5]. This article will delve into the specifics of K-type thermocouples (Fig. 2), their application in water level measurement, and the practical differences between 2-wire and 3-wire connections as illustrated in Fig. 3.

HJTCs are designed to withstand the harsh conditions inside nuclear reactors, where temperatures and radiation levels can be extreme as illustrated in Fig. 4. They are typically used in critical applications such as monitoring water levels, which is vital for reactor core cooling and overall operational stability.

HJTCs are vital temperature sensors used in nuclear reactors, including PWRs and BWRs. These thermocouples are designed to accurately measure temperature in extreme environments, where high temperatures and radiation levels are prevalent. The heated junction, located at the tip of the thermocouple, allows for precise temperature detection, which is crucial for maintaining safe operating conditions and ensuring reactor cooling. HJTCs, especially those of K-type, offer robust performance in these challenging conditions, providing reliable data for reactor control systems.

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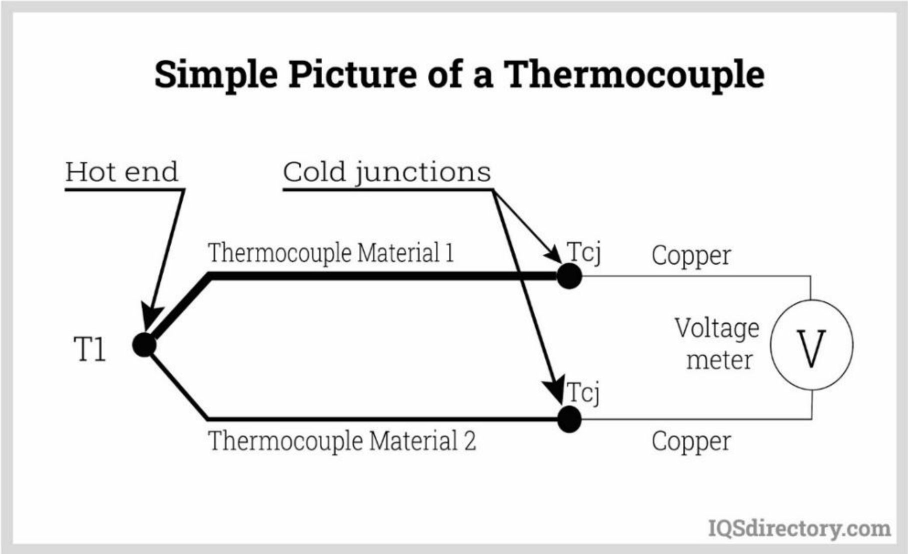

Fig. 1 A simple illustration of thermocouple.
(Source: IQSdirectory.com)

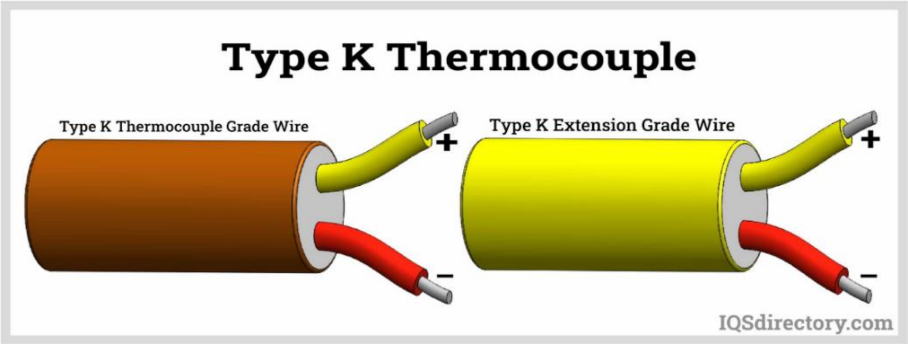

Fig. 2 A simple illustration of K-type thermocouple.
(Source: IQSdirectory.com)

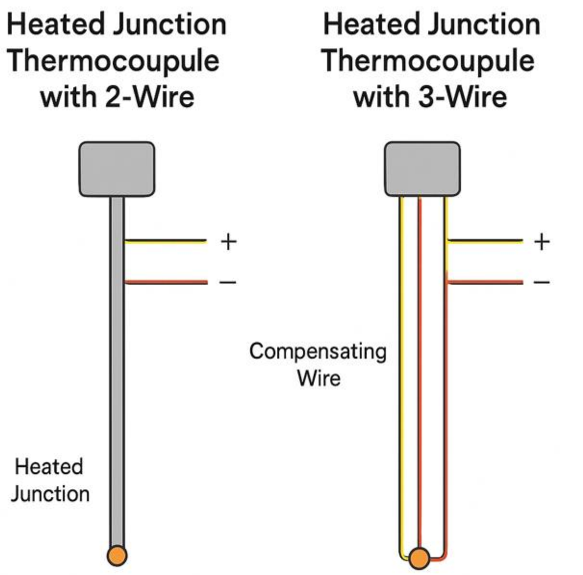

Fig. 3 HJTC of 2-wires and 3-wires K-type.
(Source: AI generated illustration)

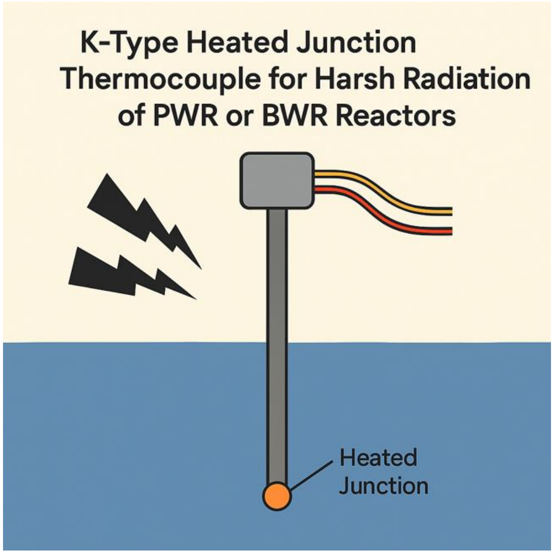

Fig. 4 The illustration of the K-type HJTC for harsh radiation environments in PWR or BWR reactors.
(Source: AI generated illustration)

2. Application in PWR and BWR Reactors

In both PWR (Fig. 5) and BWR (Fig. 6), water level measurement is crucial for maintaining the reactor's core cooling system and ensuring that the nuclear fuel remains adequately submerged. K-type thermocouples are preferred for their reliability and accuracy in measuring temperatures within the reactor vessel.

3. The Role of Heated Junctions

HJTCs utilize a heated junction to maintain a constant temperature difference between the measurement junction and the reference junction. This feature is essential in environments where temperature variations could affect measurement accuracy.

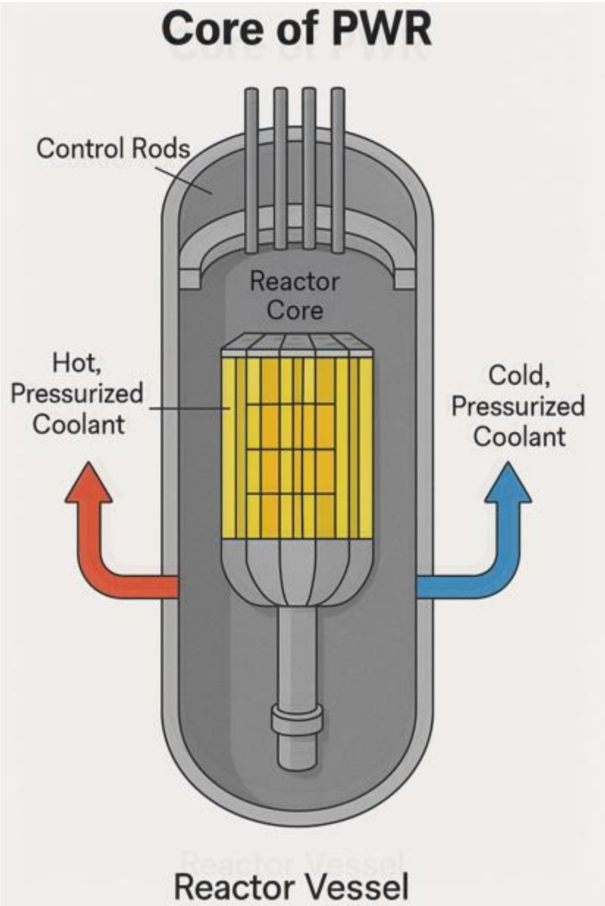

Fig. 5 Core of PWR.
(Source: AI generated image)

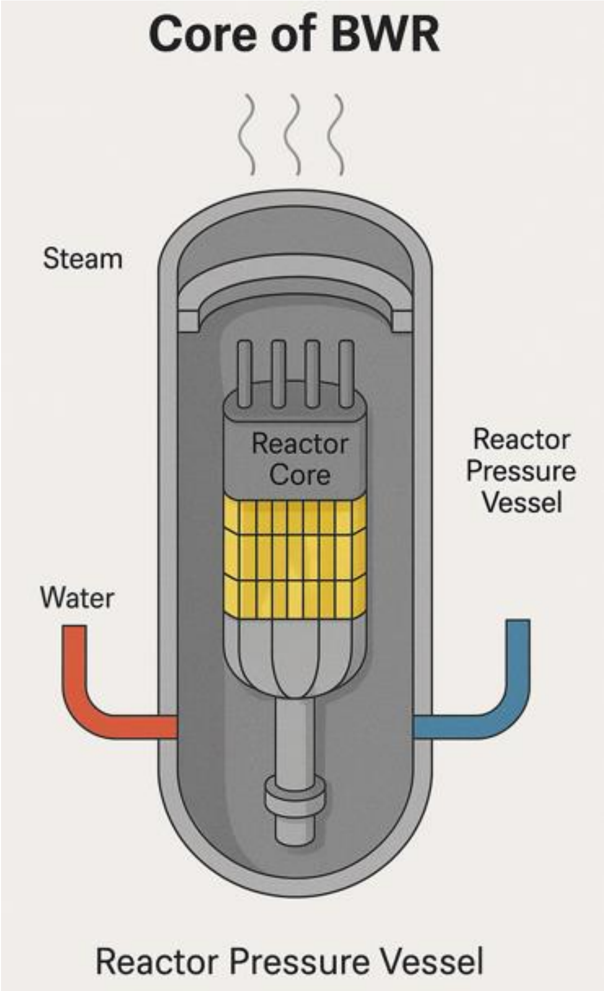

Fig. 6 Core of BWR.
(Source: AI generated image)

4. Difference between 2-Wire and 3-Wire Connections

Holistically, the difference between 2-wire and 3-wire connections are described as follows and depicted in Fig. 3.

4.1 2-Wire Connection

A 2-wire thermocouple connection consists of a single pair of wires—one for the positive and one for the negative lead. This configuration is simple and cost-effective but is susceptible to inaccuracies due to wire resistance. The resistance of the wires affects the accuracy of temperature measurement, especially over long distances.

4.2 3-Wire Connection

A 3-wire thermocouple connection uses three wires: two for the thermocouple circuit (positive and negative) and a third compensating wire. The third wire compensates for the lead wire resistance, thereby minimizing errors caused by lead resistance. This configuration provides more accurate temperature readings, especially in environments where the length of the connecting wires is significant.

5. Practical Considerations in Nuclear Reactors

In nuclear reactor applications, accuracy and reliability are paramount. While 2-wire connections are simpler and sufficient for shorter distances or less critical measurements, 3-wire connections are preferred for more accurate and stable temperature readings, particularly in long-distance or high-precision applications like water level measurement in PWR and BWR reactors.

6. Why Is K-Type a Better Choice for a PWR or BWR?

The K-type thermocouple is often considered the best choice for use in PWRs and BWRs for several important reasons related to its performance and reliability in the harsh conditions of nuclear reactors. Below are some key factors that make the K-type thermocouple ideal for such applications.

6.1 Wide Temperature Range

The K-type thermocouple has a wide temperature range, typically from -270 °C to +1,372 °C, which makes it suitable for the high-temperature environments in PWRs and BWRs. The temperature inside these reactors can fluctuate significantly depending on reactor power output, and the K-type thermocouple can accurately measure temperatures within the required range.

6.2 High Sensitivity

K-type thermocouples offer excellent sensitivity, meaning they can detect even small changes in temperature. This is particularly crucial in reactor environments where temperature changes must be monitored with precision for safety and efficiency.

6.3 Robustness and Durability

K-type thermocouples are made of chromel (nickel-chromium alloy) and alumel (nickel-aluminum alloy), which are highly resistant to oxidation and corrosion. In the extreme radiation, pressure, and thermal conditions inside nuclear reactors, K-type thermocouples provide a high degree of durability, making them ideal for long-term, reliable operation.

6.4 Cost-Effectiveness

Compared to other thermocouple types, such as platinum-based thermocouples, the K-type is relatively affordable. This makes it an attractive option for use in large-scale nuclear reactor systems, where numerous temperature sensors are required to monitor various parameters.

6.5 Resistance to Radiation

The materials used in K-type thermocouples are resistant to radiation-induced damage, which is a critical factor in nuclear reactor environments. Over time, the high radiation exposure in a reactor can degrade the performance of certain materials, but the K-type thermocouple maintains its accuracy and reliability even in these harsh conditions.

6.6 Availability and Standardization

K-type thermocouples are widely available and standardized, making them easier to source and replace. Their compatibility with existing instrumentation and measurement systems is another reason they are frequently chosen for reactor applications.

6.7 Accuracy and Stability

K-type thermocouples provide high accuracy and stable readings, which are essential for ensuring safe reactor operation. Monitoring temperature in real-time is crucial for detecting anomalies that could affect the reactor's cooling and safety systems. The accuracy of K-type thermocouples ensures that operators can make timely adjustments and take necessary precautions.

6.8 Ease of Integration

K-type thermocouples are compatible with a wide range of data acquisition and control systems commonly used in PWRs and BWRs. This ease of integration into reactor control systems is crucial for efficient monitoring and control of reactor temperature.

7. HJTC Final Assembly Configuration PWR and BWR RPV

The choice of a HJTC being placed in a wet tube or similar protective sheath is crucial for ensuring better resistance and resiliency in the harsh environment of PWRs and BWRs. The RPV (reactor pressure vessel) of these reactors exposes sensors to extreme conditions, including high temperatures, intense radiation, and aggressive corrosion potential.

Here is why using a wet tube or protective sheath is important:

(1) Corrosion Resistance

In both PWR and BWR reactors, the reactor coolant is often water, which can contain aggressive chemicals such as boron or dissolved oxygen. These can lead to corrosion, especially in the high-temperature and high-pressure environment inside the reactor. A wet tube (often made of corrosion-resistant materials like stainless steel or zirconium alloys) acts as a protective barrier for the thermocouple, preventing corrosion from compromising the sensor's performance over time.

(2) Radiation Protection

Both PWRs and BWRs operate in environments with high levels of neutron and gamma radiation. Continuous radiation exposure can degrade the materials of unprotected thermocouples, reducing their lifespan and accuracy. The wet tube provides shielding, thereby extending the durability of the HJTCs by minimizing direct radiation damage to the sensor materials.

(3) Thermal Insulation

The wet tube helps in insulating the thermocouple from thermal fluctuations and ensures that the sensor remains accurate and stable over time. In reactors, the temperature gradient within the pressure vessel can be steep. A protective sheath ensures that the temperature at the measurement point is not affected by external thermal gradients, thus providing more accurate temperature readings.

(4) Mechanical Protection

Inside the reactor, there can be mechanical stresses such as pressure pulses, vibration, and even shocks. The wet tube serves as a mechanical shield, protecting the sensitive thermocouple elements from these stresses that could otherwise lead to physical damage or failure.

(5) Prevention of Contamination

The harsh environment inside the reactor could also result in contamination from radioactive materials. The wet tube serves as a containment structure, preventing the thermocouple from coming into direct contact with the coolant or other materials that could lead to contamination or degradation of the sensor's performance.

(6) Improved Long-Term Resiliency

The reactor environment is not only harsh but also continuous. The combination of elevated temperature, pressure, radiation, and chemical aggression demands sensors that can perform reliably over many years. A wet tube sheath enhances the long-term resiliency of the thermocouple, ensuring it remains functional without requiring frequent replacements or recalibration.

In summary, using a wet tube or protective sheath for HJTCs as illustrated in Fig. 7, in the harsh environment of PWR and BWR, RPV is essential for ensuring resistance to corrosion, radiation, and mechanical damage, while also maintaining accurate and stable performance over the long term. The protective tube plays a vital role in enhancing the durability, resilience, and longevity of the thermocouple sensor, making it a critical component in nuclear reactor instrumentation.

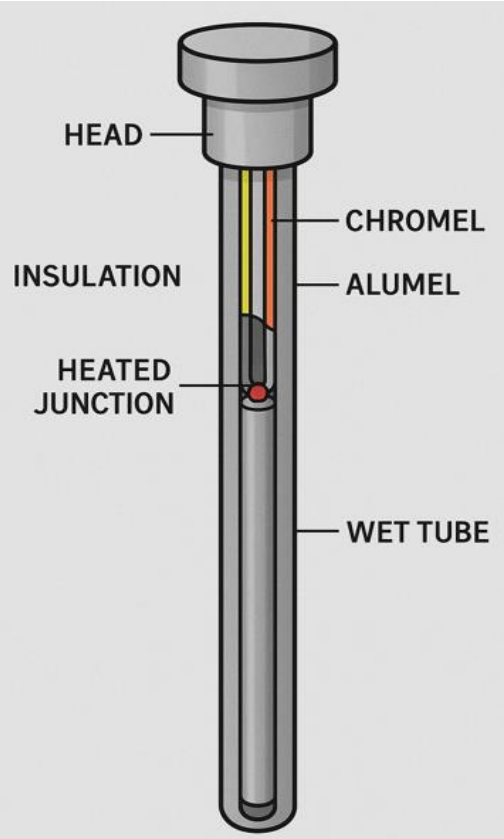

Fig. 7 The detailed illustration of the K-type HJTC assembly in a wet tube.
(Source: AI generated image)

8. Conclusion

HJTCs, particularly K-type thermocouples, are indispensable tools in nuclear reactor instrumentation, especially for monitoring water levels in PWR and BWR reactors. Understanding the difference between 2-wire and 3-wire connections is crucial for ensuring accurate and reliable temperature measurement, which directly impacts reactor safety and operational efficiency.

Due to their wide temperature range, robustness, radiation resistance, cost-effectiveness, and reliability, K-type thermocouples are an excellent choice for measuring temperature in the high-pressure, high-radiation environment of PWRs and BWRs. These thermocouples help ensure that reactor temperatures are maintained within safe operating limits, contributing to the overall safety and efficiency of the nuclear reactor.

This article provides an overview of their application, differences in wiring configurations, and emphasizes the importance of accurate temperature measurement in nuclear reactor environments [6-10].

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