

Reliability Improvement of TC Input Module of Nuclear Power Plant Safety-Grade PLC through Cold Junction Voting Algorithm

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1. Introduction

The accuracy and reliability of temperature measurements are critical factors in safety systems. In particular, thermocouple(TC) based temperature measurement systems are widely used across various fields due to their high durability and broad measurement range [1]. For temperature measurement in nuclear power plants, TC input modules are incorporated into safety-grade PLC [2,3]. However, the Cold Junction(CJ) in TC input modules can experience a decrease in reliability due to sensor aging. Existing CJ compensation methods rely on a single measurement value, which creates a limitation where the reliability of the entire system significantly decreases if an issue occurs with a specific sensor.

This study proposes adding a Voting function to the TC input module to address these issues. The Voting function uses data from multiple CJ sensors to determine a more reliable temperature value, effectively detecting and correcting sensor errors. The goal of this research is to ensure the high reliability required for safety-grade control devices and enhance the performance of TC input modules.

2. Methods and Results

2.1 Limitations of Existing Reliability in TC Input Modules

A thermocouple measures the temperature difference between the measurement point and the reference point rather than the absolute temperature. Therefore, the temperature of the dissimilar metal junction must be obtained through a PT100 sensor measurement (CJ measurement) and subtracted from the measured temperature of the channel to ensure accurate compensation [4]. In TC input modules, Cold Junction (CJ) measurement points are positioned at both the top and bottom of the module to calculate the temperature for each channel. However, if a failure occurs in one or more PT100 sensors or the associated circuitry, resulting in a significant discrepancy between the two sensor readings, it becomes challenging to determine which value is more reliable. Consequently, effectively mitigating sensor-induced errors remains a critical limitation.

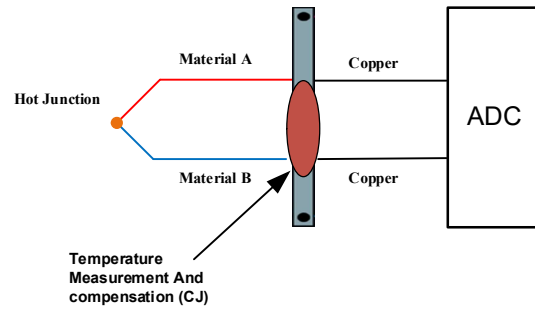


Fig. 1. Operating Principle of Thermocouple

2.2 Voting Function and Expected Benefits

Adding a Voting function can improve the reliability of the TC input module. By using three CJ sensors to calculate the average value or applying error correction algorithms, more accurate temperature measurements can be achieved. If a specific sensor malfunctions or outputs abnormal values, errors can be detected and automatically corrected by comparing the values of the other sensors, thus enhancing the stability and durability of the system.

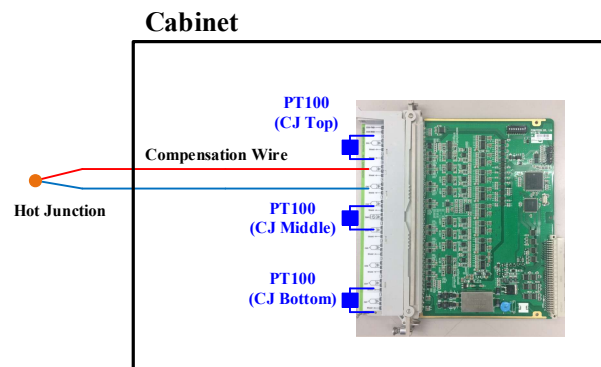


Fig. 2. TC Input Module's Three CJ Sensor Structure

Furthermore, applying a Voting algorithm based on multiple sensors ensures strong reliability even in the face of sensor aging. This enables the TC input module to more effectively meet the requirements of safety-grade control devices.

2.3 Voting Algorithm

The operating algorithm of the proposed TC input module with the voting function is designed to improve the reliability of CJ temperature estimation by using three redundant CJ sensors. In the revised method, the final CJ temperature is not determined by simply removing an extreme value. Instead, each sensor measurement is evaluated using multiple validity criteria, including the allowable operating range, temporal continuity, and mutual consistency among the three sensors.

First, temperature data are collected from the three CJ sensors. Each sensor output is checked to ensure that it remains within the allowable operating range of the module. The sensor outputs are also monitored over time to detect abrupt variations that are physically unlikely. In addition, the three sensor readings are compared with one another to determine whether they remain mutually consistent. To prevent transient noise from being misinterpreted as a sensor fault, an abnormal condition is confirmed only when the inconsistency persists over consecutive measurements.

If all three sensors satisfy the validity conditions and remain mutually consistent, the final CJ temperature is obtained by averaging the three measurements. If one sensor is identified as faulty because it persistently deviates from the other two, that sensor is excluded, and a new average is calculated using only the remaining two valid sensors. If two or more sensors violate the validity criteria, the algorithm classifies the condition as a multiple-fault case and places the module in a protective handling mode, such as warning generation or hold-last-valid compensation, instead of applying an unreliable compensation value.

This approach improves the robustness of CJ compensation not only against obvious extreme outliers but also against non-extreme fault conditions such as bias errors or drift. As shown in Fig. 3, the proposed algorithm performs sensor validation and fault classification before calculating the final CJ compensation value.

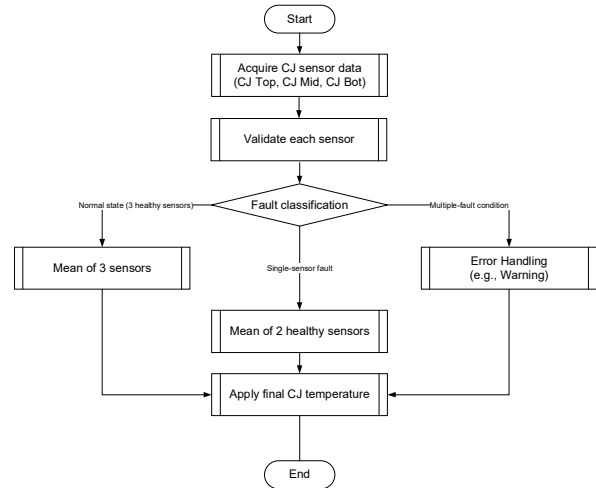


Fig. 3. Proposed three-CJ-sensor voting algorithm with sensor validation and fault handling.

In a three-sensor redundancy structure, a single faulty sensor can be isolated through pairwise consistency analysis. However, when two sensors fail simultaneously, the healthy sensor cannot always be uniquely identified using instantaneous sensor values alone. Therefore, the proposed method does not attempt full fault isolation in such cases. Instead, when fewer than two valid sensors remain, the module enters a protective handling mode, such as warning generation, hold-last-valid compensation, or maintenance request signaling.

By applying the proposed multi-criteria voting algorithm, small measurement errors caused by sensor location differences and temporary disturbances can be reduced while maintaining robustness against sensor faults. As a result, the TC input module can obtain more reliable CJ temperature values, thereby improving the accuracy and stability of temperature measurement.

3. Conclusions

The proposed TC input module with the voting function improves the reliability of CJ temperature estimation by using three redundant CJ sensors and a multi-criteria validation algorithm. Unlike a simple extreme-value rejection scheme, the proposed method evaluates sensor outputs based on operating range, temporal continuity, and mutual consistency, allowing robust compensation under normal and single-fault conditions. In addition, multiple-fault situations are handled through a protective mode rather than unreliable compensation, which improves the overall reliability and stability of temperature measurement in safety-grade PLC applications.

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