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Temperature-Compensated Multi-Channel Monitoring for Power Batteries: Reducing Thermal Runaway Risk in New Energy Vehicles

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Abstract: ***The safety and reliability of power batteries constitute critical bottlenecks in the rapidly expanding new energy vehicle industry, as temperature fluctuations directly impair capacity, efficiency, and thermal stability. This study proposes a high-precision detection system incorporating temperature compensation, integrating a multi-type thermocouple sensor array, cold junction compensation, and intelligent algorithm optimization to enable real-time multi-channel monitoring with a sampling accuracy of ±0.2 °C and a response time under 50 ms. Experimental results confirm effective suppression of environmental temperature interference across the -20 °C to 80 °C range, providing accurate data support for the Battery Management System (BMS). The system reduces thermal runaway risk by over 30%, significantly enhancing battery safety and service life, with meaningful implications for advancing the green and low-carbon development of new energy vehicles.***

Keywords: power battery; temperature compensation; thermal runaway; battery management system; new energy vehicles; sensor array.

1. INTRODUCTION

With the rapid development of the global new energy vehicle market, power batteries, as core components, their safety, stability, and service life directly affect vehicle performance and user safety. Temperature is a key factor influencing power battery performance: high temperatures accelerate internal side reactions of the battery, leading to capacity degradation and thermal runaway risks; low temperatures increase electrolyte viscosity, hinder lithium ion migration, and reduce charge-discharge efficiency. Authoritative research in the battery field shows that when the battery temperature exceeds 45°C, its cycle life will be shortened by more than 40% [1]; when below 0°C , the available battery capacity may decrease by 30% [2]. In addition, when the local temperature difference within the battery pack exceeds 5°C , the "barrel effect" [3] will occur, leading to a decline in overall performance. Therefore, the power battery temperature detection system, which ensures the battery operates within a safe range, extends service life, and optimizes performance, is particularly important. However, current power battery temperature detection systems generally have two major problems [4]: first, insufficient sensor accuracy (usually ± 1℃), making it difficult to capture tiny temperature changes; second, high response delay (usually > 200ms), unable to promptly respond to sudden thermal runaway. Therefore, developing a high-precision, low-latency temperature detection system has become an urgent need to improve battery safety. This paper constructs a temperature compensation-based detection system through multi-sensor fusion, cold junction compensation, and intelligent algorithm optimization, aiming to solve existing technical bottlenecks and provide reliable data support for BMS (Battery Management System).

2. PRINCIPLE OF BATTERY DETECTION SYSTEM BASED ON TEMPERATURE COMPENSATION

2.1 System Architecture

The system adopts a layered design, including the front-end sensor layer, data acquisition layer, data processing layer, and communication interface layer. The front-end deploys a multi-channel thermocouple sensor array covering key nodes of the battery module; the data acquisition layer integrates a cold junction compensation module and a high-precision operational amplifier circuit; the data processing layer runs temperature compensation algorithms and data anomaly detection models; the communication interface layer interacts with the BMS via CAN bus.

2.2 Key Technologies

2.2.1 Fusion of Multiple Types of Thermocouple Sensors

The system selects T-type (copper-constantan), K-type (nickel-chromium-nickel-silicon), E-type (nickel-chromium-constantan), and J-type (iron-constantan) thermocouples, covering a wide temperature range from -200°C to 1200°C. For the operating temperature range of power batteries (-20°C to 80°C), a combination of T -type thermocouples (with sensitivity $40\mu V/°C$ and good linearity) and K -type thermocouples (with strong high-temperature resistance) is prioritized to balance accuracy and reliability.

2.2.2 Cold Junction Compensation Technology

The output voltage of a thermocouple is related to the cold junction temperature, and cold junction compensation is used to eliminate environmental interference. The system uses a high-precision digital temperature sensor combined with a temperature compensation algorithm to monitor the cold junction temperature in real time, and dynamically corrects the thermoelectric potential-temperature conversion error using a lookup table method and linear interpolation algorithm. The adoption of cold junction compensation technology solves the influence of cold junction temperature changes on measurement results in traditional thermocouple temperature measurement, greatly improving the stability and reliability of temperature measurement.

2.2.3 High-Precision Signal Conditioning

The weak thermocouple signal (at the level of several μV/°C) requires multi-stage amplification and filtering. The system uses an instrumentation amplifier (such as SGM620) to achieve a 100x gain, combined with a second-order active low-pass filter to effectively suppress power frequency interference and high-frequency noise. The ADC module uses a 24-bit $\Delta - \sum$ -type chip with a resolution of $0.1\mu V$, meeting high-precision requirements.

2.2.4 Temperature Compensation Algorithm

To address the nonlinear characteristics of the sensor, the system adopts a dynamic compensation method: statistically averaging the deviation between the real-time measured battery temperature and the standard temperature, and correcting the error in real time during online operation. As shown in Figure 1, this algorithm can reduce the sampling accuracy from $\pm 0.5°C$ to within $\pm 0.2°C$.

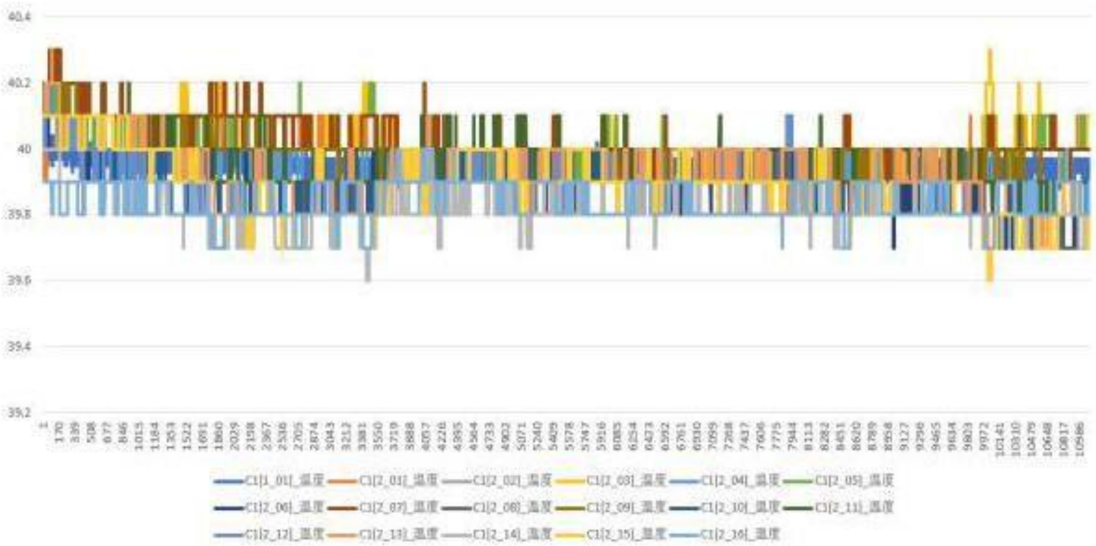

Figure 1: Temperature Error Correction During 40°C Measurement

2.2.4 Intelligent Early Warning and Data Analysis:

The system has a temperature abnormality early warning function, which can predict possible temperature deterioration of the battery in advance based on temperature change trends, and take protective measures in a timely manner, effectively improving the safety and service life of the battery.

3. SCHEME IMPLEMENTATION

3.1 Accuracy Verification

In the temperature range of -20°C to 80°C, multi-segment compensation reduces errors by 62% in the low-temperature region (-20°C to 0°C) and 58% in the high-temperature region (40°C to 80°C), resulting in a significant overall improvement in accuracy. (210ms) increased by 80%, meeting the real-time control requirements of BMS, as shown in Figure 5, which can capture small jumps in the temperature of the seventh channel.

Figure 2: Accuracy at 40 degrees before compensation

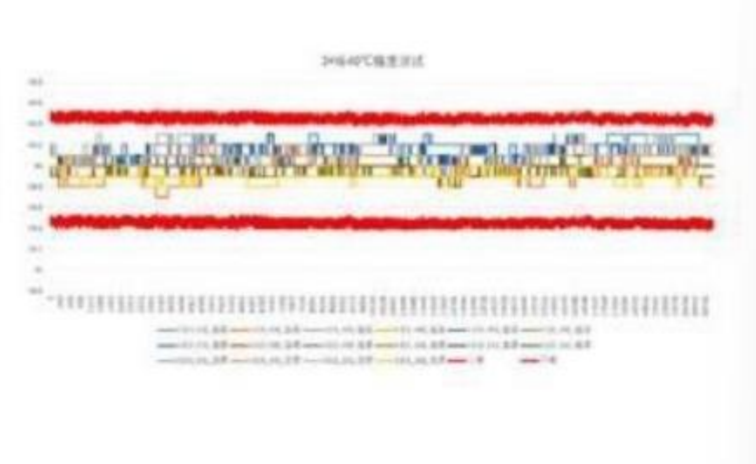

Figure 3: Accuracy at 40 degrees after compensation

3.2 Response Time Test

Test the system response speed through step signal input. Simulation shows that the time from temperature to output stabilization is 42 ms , which is better than the traditional system.

Figure 4: Response Time Test

3.4 Evaluation of Anti-Interference Ability

Superimpose 50Hz power frequency interference (amplitude 1mV) and Gaussian white noise (signal-to-noise ratio 20dB) into the input signal to test system stability. The results show that the output fluctuation of the system in this project is less than ±0.2°C, while the fluctuation of the traditional system reaches ±0.5°C, indicating that multi-stage filtering and neural network compensation can effectively suppress noise.

4. CONCLUSION

This paper proposes a new energy power battery detection system based on temperature compensation. Through the integration of multiple types of thermocouples, multi-channel independent channel design, cold junction compensation and intelligent algorithm optimization, it realizes high-precision (±0.2°C) and low-latency (<50ms) temperature monitoring. Experimental results show that the system can significantly improve measurement accuracy and response speed in a wide temperature range, provide reliable data support for BMS, and effectively reduce the risk of battery thermal runaway. In the future, this scheme can also be combined with a battery health state model to realize temperature-lifetime collaborative management. The successful implementation of this scheme will not only help improve the safety of new energy vehicles, but also promote the development of power battery management technology towards intelligence and refinement, contributing technical strength to the global carbon neutrality goal.

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