

Influence of DC Power Supply on Thermoelectric Cooler Cooling Performance: Voltage Stabilization vs. Constant Current Power Supply



1. Abstract

The cooling stability, temperature control accuracy, and long-term operational reliability of thermoelectric cooler (Peltier) chips are directly affected by DC power supply modes. Thermoelectric cooler chips feature a unique dynamic temperature-resistance characteristic, resulting in substantial differences in operating mechanisms, cooling performance, and scenario adaptability between regulated voltage power supply and constant current power supply. This paper focuses on studying the influence of power supply modes on the cooling stability of thermoelectric coolers. It

systematically compares the advantages and disadvantages of voltage-stabilized and constant-current power supply modes, verifies the interference law of voltage fluctuation on cooling temperature difference through experimental tests, proposes optimal power supply matching schemes for different operating conditions, and finally defines standardized power supply selection criteria for thermoelectric cooler systems, providing technical references for the design and engineering implementation of semiconductor cooling power systems.

Keywords: thermoelectric cooler power supply; semiconductor refrigeration power supply mode

2. Operating Characteristics, Advantages and Disadvantages of Voltage-Stabilized Power Supply

Voltage-stabilized power supply is the most fundamental and widely adopted DC power supply mode for thermoelectric cooler cooling systems. It maintains a constant output voltage, while the output current adjusts dynamically according to the internal resistance, temperature and load changes of thermoelectric cooler chips. Featuring a simple circuit structure and convenient debugging, it is universally applied in conventional semiconductor refrigeration equipment.

2.1 Core Operating Characteristics

The internal resistance of thermoelectric cooler chips varies significantly with operating temperature, presenting an obvious temperature-resistance correlation. At the initial startup stage, the chip is at room temperature with minimum internal resistance, generating an instantaneous peak current and high startup power. As cooling proceeds, the temperature difference between the cold and hot ends of the thermoelectric cooler gradually forms, the overall chip temperature rises, and the internal resistance of thermoelectric grains increases continuously. Under a constant voltage, the operating current decreases with rising resistance, forming a typical operating feature of **high current at startup and current attenuation in steady state**. This mode locks the output voltage within the rated range, effectively preventing overvoltage breakdown with simple control logic and no requirement for high-precision closed-loop regulation.

2.2 Core Advantages

First, it delivers high operational safety and fault tolerance. Voltage-stabilized power supply limits the maximum output voltage at the hardware level, eliminating chip breakdown, solder joint burnout and insulation failure caused by overvoltage operation, and is highly compatible with basic cooling equipment without complex protection circuits. Second, it is low-cost and highly versatile. The voltage stabilization circuit features simple structure, low mass production cost and low debugging difficulty, requiring no precise matching with thermoelectric cooler parameters and suitable for mass production of small civil cooling equipment. Third, it ensures stable startup and adapts to intermittent operating conditions with no abnormal current impact during startup and shutdown, perfectly fitting short-term and

discontinuous cooling scenarios.

2.3 Main Disadvantages

The primary shortcoming of voltage-stabilized power supply is insufficient cooling stability and obvious temperature difference attenuation during long-term operation. When the equipment enters steady-state cooling, the continuous rise of thermoelectric cooler internal resistance reduces the operating current and cooling power, leading to cold end temperature rise and temperature control accuracy drift. Under long-term continuous cooling and high-load heat dissipation fluctuation conditions, cooling attenuation is particularly prominent, making it impossible to maintain a constant temperature and failing to meet the high-precision temperature control demands of industrial precision instruments, medical equipment and laser devices.

3. Analysis of Applicable Working Conditions for Constant-Current Power Supply

Constant-current power supply is an optimized advanced power supply scheme tailored to the dynamic temperature-resistance characteristics of thermoelectric coolers. It locks the output current at a constant value, while the output voltage adjusts adaptively with changes in chip internal resistance and temperature. This perfectly compensates for the steady-state defects of voltage-stabilized power supply, targeting high-precision, high-stability and long-term continuous cooling working conditions.

3.1 Operating Characteristics of Constant-Current Power Supply

Constant-current power supply drives thermoelectric cooler chips with a fixed current, independent of changes in chip temperature and internal resistance. In the initial startup stage with low chip internal resistance, the power supply automatically reduces the output voltage to avoid current overload. In the later operating stage with increased chip temperature and internal resistance, the power supply actively raises the output voltage to maintain a constant operating current. This working mechanism eliminates power attenuation caused by the temperature-resistance characteristics of thermoelectric coolers, ensuring stable cooling power and minimal temperature difference fluctuation between cold and hot ends.

3.2 Core Applicable Working Conditions

Constant-current power supply adapts to industrial continuous operation scenarios with strict requirements for temperature control accuracy and stability, including laser equipment temperature control, precision testing instrument constant temperature systems, medical refrigeration equipment, and industrial online temperature control modules that work 24/7. These scenarios prohibit temperature difference drift and power attenuation and require extremely high power supply stability, making them the core application fields of constant-current power supply.

3.3 Working Condition Limitations

Constant-current power supply has obvious application limitations and high startup risks. At room temperature, the internal resistance of thermoelectric coolers is the lowest. To maintain a constant current, the power supply will instantly raise the output voltage, which may easily exceed the chip withstand voltage threshold and cause breakdown and burnout. Thus, an upper voltage limit protection circuit is mandatory. In addition, constant-current power supplies feature complex circuit design and higher costs, with unnecessary power consumption under short-term startup-shutdown and intermittent light-load conditions, making them unsuitable for ordinary civil low-end cooling equipment.

4. Experimental Test on the Influence of Voltage Fluctuation on Temperature Difference

To quantitatively compare the stability differences between the two power supply modes and verify the correlation between voltage fluctuation and thermoelectric cooler cooling temperature difference, this paper conducts comparative tests using the mainstream industrial thermoelectric cooler 12706 chip. With unified ambient temperature and heat dissipation conditions to simulate real engineering working conditions, the test measures temperature difference changes under voltage fluctuation and constant-current steady-state operation.

4.1 Test Conditions

Test chip: Thermoelectric Cooler 12706 Peltier chip; Ambient temperature: 25°C constant temperature indoor environment; Heat dissipation configuration: Standard aluminum heat sink + constant-speed cooling fan; Test indicators: Instant startup temperature difference, steady-state continuous temperature difference, 30-minute temperature difference attenuation rate, and anti-interference capability against voltage fluctuation.

4.2 Test Results of Voltage Fluctuation under Voltage-Stabilized Power Supply

With a fixed 12V regulated power supply, the instantaneous startup current reaches 5.7A and the maximum instantaneous cold-hot temperature difference hits 42°C. After 10 minutes of continuous operation, chip temperature rise increases internal resistance, the current attenuates to 4.1A, and the temperature difference drops to 32°C. After 30 minutes of continuous operation, the steady-state temperature difference decreases to only 27°C, with an overall temperature difference attenuation rate exceeding 35%. With a conventional $\pm 1V$ voltage fluctuation, the temperature difference fluctuation amplitude exceeds 7°C, resulting in poor temperature control accuracy and insufficient steady-state stability.

4.3 Steady-State Test Results of Constant-Current Power Supply

With a fixed 4.5A constant-current power supply, the adaptive startup voltage is 6.1V with an initial temperature difference of 41°C. After 30 minutes of continuous operation, the power supply adaptively boosts voltage to match increased internal resistance, maintaining a constant current throughout the test. The final steady-state temperature difference stabilizes at approximately 39°C, with an overall attenuation

rate below 5%. Even with slight voltage and heat dissipation fluctuations, the temperature difference variation is controlled within 1°C, delivering far better anti-interference performance than the voltage-stabilized mode.

4.4 Test Conclusions

Voltage fluctuation and dynamic changes in thermoelectric cooler internal resistance are the core causes of cooling temperature difference drift. Voltage-stabilized power supply cannot compensate for power attenuation induced by temperature-resistance characteristics, resulting in severe long-term temperature difference attenuation and weak anti-fluctuation capability. In contrast, constant-current power supply adapts to thermoelectric cooler thermoelectric characteristics through adaptive voltage adjustment, effectively suppressing temperature difference drift and serving as a reliable power supply solution for high-precision temperature control scenarios.

5. Optimal Power Supply Scheme Matching Suggestions

Combined with the operating characteristics and test data of voltage-stabilized and constant-current power supplies, three optimal power supply matching schemes are summarized for different application scenarios, operating modes and accuracy requirements, balancing safety, stability and economy for multi-level semiconductor cooling system design.

5.1 Conventional Civil Scenarios: Pure Voltage-Stabilized Power Supply Scheme

For cost-sensitive civil equipment with short-term operation, intermittent startup and shutdown, and low precision requirements, such as small vehicle-mounted cooling boxes, household cooling modules and ordinary smart home cooling devices, the pure voltage-stabilized power supply scheme is preferred. With a simple structure, high safety and high cost performance, it meets conventional cooling demands and operates stably with basic overcurrent protection.

5.2 Industrial Precision Scenarios: Pure Constant-Current Power Supply Scheme

For 24-hour continuously operated industrial equipment requiring high-precision constant temperature and low drift, such as laser temperature control systems, medical instruments and precision testing equipment, a constant-current power supply scheme with upper voltage limit protection is mandatory. Relying on the steady-state advantages of constant-current power supply, it completely eliminates power attenuation and temperature difference drift, ensuring long-term high-precision constant temperature operation.

5.3 High-End Complex Scenarios: Intelligent Voltage-Stabilized & Constant-Current Switching Scheme

For high-end industrial temperature control equipment and all-weather complex operating conditions, an intelligent dual-mode power supply strategy is

recommended. The system adopts voltage stabilization and current limiting at the startup stage to avoid instantaneous high voltage and large current impact and protect the chip; it automatically switches to constant-current mode after reaching steady state to lock cooling power and maintain long-term temperature stability. Integrating the advantages of both power supply modes, this scheme is currently the optimal comprehensive power supply solution for thermoelectric cooler systems.

6. Conclusion: Power Supply Selection Criteria for Different Scenarios

Based on the comprehensive characteristic analysis and experimental data comparison, the power supply selection for thermoelectric cooler semiconductor cooling systems shall be standardized according to four core dimensions: operating duration, temperature control accuracy, working condition and cost budget, forming clear scenario-based selection criteria.

First, voltage-stabilized power supply is the optimal choice for intermittent short-term, low-cost and general cooling scenarios. It features stable startup, simple structure, low failure rate and high cost performance, fully meeting the conventional cooling demands of civil small and medium-sized Peltier cooling equipment.

Second, constant-current power supply with protection circuits is mandatory for long-term continuous, high-precision industrial-grade constant temperature scenarios. Voltage-stabilized power supply fails to meet the steady-state temperature control requirements of high-precision equipment, while constant-current power supply offsets power attenuation caused by the dynamic internal resistance of thermoelectric coolers to ensure stable temperature difference and controllable accuracy, which is a necessity for industrial precision temperature control.

Third, the dual-mode switching scheme of voltage stabilization and constant current is preferred for high-reliability, all-weather and high-end complex working conditions, balancing startup safety and steady-state stability, maximizing the service life of thermoelectric cooler chips and improving the overall reliability of the temperature control system.

Overall, the cooling stability of thermoelectric coolers depends on the precise matching between power supply mode and working conditions. Reasonable selection of DC power supply modes can fundamentally solve common engineering problems such as cooling drift, power attenuation and chip damage.

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