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Design of a Monitoring System for a Burn-in Furnace with Heat Dissipation and Temperature Control

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The burn-in test system is an indispensable piece of equipment in the reliability testing of electronic products. It is designed to simulate high-temperature environments to conduct long-term stability tests on electronic components. This helps identify potential defects early and enhance product quality before they reach the consumer market. Traditional burn-in chambers, however, often face issues such as inadequate control accuracy, energy wastage, and low safety standards. To address these challenges, in this paper, we present the design and implementation of a burn-in furnace monitoring system based on a programmable logic controller (PLC) for heat dissipation and constant temperature control. The system places a PLC at its core as the central control unit. It continuously monitors the temperature inside the chamber in real time using temperature sensors, ensuring that the test environment remains stable. By coordinating the operation of both heaters and exhaust fans, the system can achieve precise temperature control and efficient ventilation management. This sophisticated system ensures optimal conditions for testing, enhancing the accuracy of results. Moreover, the system incorporates a well-designed safety protection mechanism, including over-temperature alarms and automatic shutdown functions, which safeguard the stability of the test process and the safety of operators. This proactive approach significantly reduces risks and improves the overall efficiency and reliability of the burn-in test system.

1. Introduction

Burn-in testing, as a widely used and effective reliability testing method, plays a critical role in the quality assurance of electronic products.(1) A burn-in test is a reliability testing process used to detect early failures in electronic components by operating them under elevated stress conditions such as high temperature, voltage, or load for an extended period. This process helps

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identify and eliminate defective units that may fail shortly after deployment, thereby improving overall product quality and reliability. During the burn-in test, devices are continuously powered and monitored to ensure they maintain stable performance. By simulating real-world or accelerated conditions, manufacturers can uncover potential weaknesses that are not evident under normal testing. Although it increases production time and cost, the burn-in test is widely used in industries such as aerospace, automotive, and semiconductor manufacturing to ensure long-term product performance and reduce the risk of field failures. This testing method involves running electronic components in high-temperature environments for extended periods, simulating their performance under extreme conditions. This approach helps assess whether the components can operate reliably and stably, while also uncovering potential defects before they can affect the final product. Burn-in testing not only aids in identifying faulty products but also contributes to enhancing the overall stability and reliability of electronic devices, which in turn reduces after-sales costs and minimizes user losses due to product failures.(2) By identifying and addressing issues early in the production process, manufacturers can ensure high levels of product performance and customer satisfaction. As the demand for high-quality electronics increases, the evolution of burn-in testing methods will continue to be essential in ensuring the long-term reliability of electronic products.(3)

However, the temperature control systems in traditional burn-in chambers encounter several challenges in real-world applications. First, insufficient control precision leads to significant temperature fluctuations within the testing environment. These variations make it difficult to meet the high precision required for accurate testing, which can compromise the integrity of test results. Secondly, energy inefficiency is a major issue. Traditional systems often fail to coordinate heating and ventilation processes effectively, leading to excessive energy consumption, low energy utilization rates, and increased operational costs. Moreover, traditional burn-in chambers typically lack adequate safety measures, such as advanced over-temperature protection mechanisms or automated monitoring features.(4) As a result, the risk of equipment malfunction or improper handling can lead to serious safety hazards, making these systems more prone to failure and potentially costly accidents. Furthermore, the lack of automation in traditional systems requires continuous manual supervision, increasing the burden on operators and leaving room for human error.(5,6)

To overcome these challenges, there has been a growing push to develop more advanced burn-in testing systems with improved precision, energy efficiency, and safety features.(7) These newer systems are designed to offer more reliable and sustainable testing solutions, which can ultimately improve product quality and reduce overall production costs. When conducting burn-in testing on electronic products, these components must operate in high-temperature environments for extended periods to simulate their performance under extreme conditions. This process helps assess the stability of the components and identify potential defects early. Burn-in testing places strict demands on the stability of the testing environment's temperature, ventilation efficiency, and system safety. However, traditional burn-in chamber heating and exhaust systems show clear shortcomings in precise control, energy efficiency, and safety, limiting the effectiveness of the tests and the overall reliability of the systems.(8) As a result, designing a burn-in chamber heating and exhaust system based on programmable logic controller (PLC) control has become a key direction to address these issues.

The primary objective of this study is to design and implement a burn-in chamber heating and exhaust system controlled by the PLC.[9,10] By leveraging the efficient control capabilities of PLC, this system will enable precise temperature control and efficient ventilation management inside the chamber. Specifically, we aim to achieve accurate temperature regulation, improved ventilation efficiency, enhanced system stability, better energy utilization, and strengthened operational safety. The design and implementation of this system will effectively address the issues present in traditional burn-in chamber heating and exhaust systems, improving the overall performance of burn-in testing. This advancement will provide more stable, efficient, and secure technical support for the reliability testing of electronic products. This PLC-controlled system will also allow for better monitoring and fine-tuned adjustments, ensuring that the burn-in testing environment remains consistent over time, which is crucial for achieving reliable test results. Additionally, the improved energy efficiency of the system will reduce operational costs, making the testing process more sustainable. The automation of safety mechanisms and temperature regulation will further reduce the chances of human error, ensuring safer operations. Through this research, we aim to not only optimize the burn-in process but also contribute to the development of more reliable, energy-efficient, and safer testing solutions for the electronic manufacturing industry.

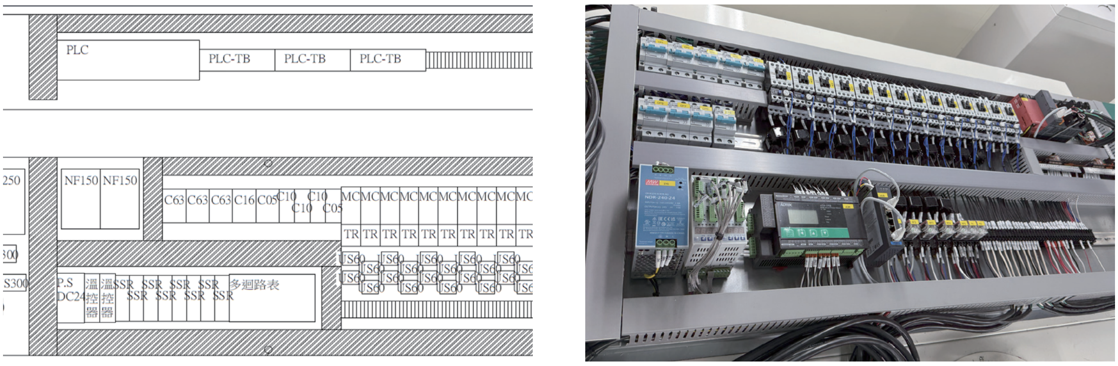
2. Basic Hardware Architecture for the Monitoring Module

In the hardware architecture of a thermal management system, the current monitoring module plays a crucial role in tracking the current across various components to ensure the system operates safely and stably, as shown in Figs. 1(a) and 1(b). The current monitoring system utilizes current transformers (CTs) for measurement. Below are the detailed introductions to each set of CTs and their monitored targets:

(a) Ten sets of CTs for monitoring device under test (DUT) current (CT-1R to CT-10R): DUT refers to the device being tested. These CTs primarily monitor the current consumption of the DUT during testing. The 10 sets of CTs may be assigned to different test channels, providing precise current measurements for each DUT's operation. This configuration allows for the collection of detailed data, helping to analyze current changes under various conditions and ensuring the stability and safety of the test environment.

(b) Two sets of CTs for monitoring heater current (CT-H1 and CT-H2): The heater is a key component in the thermal management system, responsible for generating the necessary heat to warm air or other media. These CTs monitor the heater's current consumption. Since the heater's power usage impacts the overall system's energy efficiency, monitoring its current is vital. This helps detect overloads, faults, or the need for maintenance.

(c) Five sets of CTs for monitoring exhaust and thermostat fans (CT-FN1 to CT-FN5): The primary role of the exhaust and thermostat fans is to maintain airflow within the thermal management system, ensuring even heat distribution and reducing the equipment temperature through ventilation. These five sets of CTs monitor the current consumption of these fans, reflecting their load conditions. Abnormal current readings may signal fan malfunctions or overloads, helping system operators address issues promptly and prevent overheating.



(a) (b)

Fig. 1. (Color online) Main control panel layout for (a) design drawing and (b) picture of a switching board.

(d) Design of the current monitoring module: The CTs are connected to a central monitoring module that collects and processes data. Each CT converts real-time current signals into digital signals, which are then sent to the monitoring module for processing and recording. This module can also interface with other control systems, enabling real-time alerts and automatic adjustments. For example, if the current from a CT exceeds set limits, the system can trigger an alert or initiate emergency actions.

(e) Hardware architecture diagram design: In the current monitoring circuit diagram, all CTs are connected to the monitoring module in a specific configuration. Each CT has its own current input port to send measured current signals to the monitoring module. The module may include units for data processing, filtering, and display to show and record the data.

This current monitoring system provides high-precision monitoring data, helping ensure the stability of the thermal management system, prevent overloads or failures, and provide immediate feedback for troubleshooting and maintenance.

3. Structures for Each Component and Discussion

The current monitoring module includes an electromagnetic contactor, a power supply unit, a CT, and a current controller. This module is responsible for the real-time monitoring of the current usage of the electromagnetic contactor and power supply unit, as shown in Fig. 2. The CT integrates the current data into the AC power meter, and the parameters are then transmitted back to the PLC. If any current anomaly is detected, the PLC will trigger an alarm to ensure the safe operation of the system. The design and functionality of the current monitoring module and its components are as follows:

(a) Electromagnetic contactor: An electromagnetic contactor is a switching device used to control high-power currents, typically to connect or disconnect the power supply to equipment. In this module, the electromagnetic contactor is responsible for connecting or disconnecting the current supply to each power device.

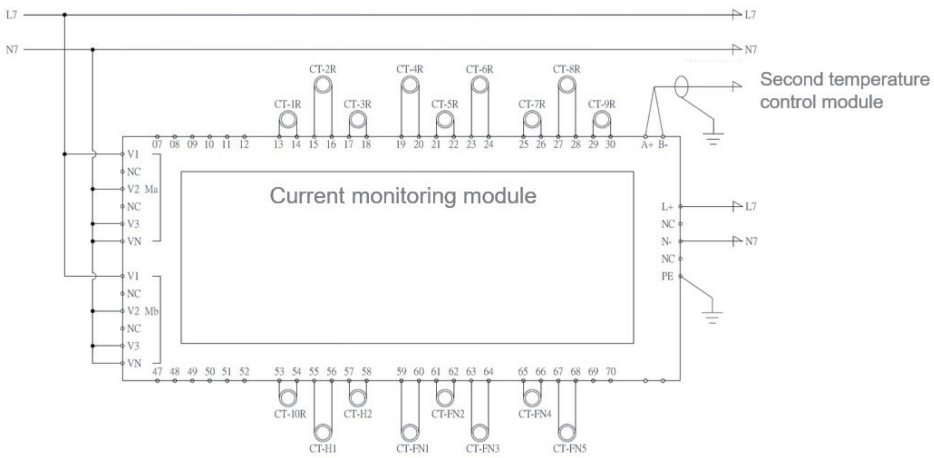


Fig. 2. Circuit diagram of the current monitoring module.

(b) Power supply unit: The power supply unit provides the necessary voltage and current to operate other electronic components in the system. In the current monitoring module, the power supply unit ensures a stable power supply for all control and monitoring equipment.

(c) CT: The CT is a device used to measure the flow of current. It can detect the magnitude of the current in real time and consolidate this data for transmission to other devices in the system. The CT sends the monitored current data to the AC power meter for detailed monitoring and data logging.

(d) Current controller: The current controller is responsible for regulating and controlling the current flowing through the system, ensuring that it remains within safe limits. It can adjust any abnormal current on the basis of the data received from the CT, allowing it to handle any overload or short-circuit situations promptly.

(e) System integration and PLC feedback: These components work together to ensure that the current flow in the entire power system remains within a safe range. Data from each component is sent back to the PLC, which processes and analyzes the data. If any anomalies are detected, the PLC triggers an alarm.

(f) Anomaly alarm system: If the monitoring module detects any abnormal conditions, such as the current exceeding the preset safe range, the system will immediately issue an alarm. This alarm will be displayed on the personal computer, alerting the operator to take immediate action to prevent equipment damage or safety incidents.

In summary, the main purpose of the current monitoring module is to ensure that the current flowing through the electromagnetic contactor and power supply unit in the system remains within the predefined safe limits. In the event of an anomaly, it provides timely warnings to the operator, ensuring the safe operation of the equipment.

In a burn-in furnace monitoring system with heat dissipation and temperature control, the design of 10 current monitoring modules for the DUT – from CT-1R to CT-10R – is a critical component aimed at ensuring the stable operation of the furnace. It detects and addresses any abnormal current conditions in a timely manner to ensure equipment safety. The design involves several key technical aspects, including an electromagnetic contactor, a power supply, a CT, and a current controller, all working together in a seamless manner. The electromagnetic contactor plays a pivotal role in the system, mainly controlling the switching of currents. During the furnace's operation, the contactor regulates the flow of current to the DUT, managing the energy distribution within the furnace. This contactor is designed for the rapid activation and deactivation of current flow, ensuring that the intended heating or testing results are achieved efficiently. The power supply is another core element of the system, providing a stable power source to the furnace while ensuring the accuracy and stability of the current. The power supply design must incorporate effective overload protection to prevent damage to equipment during high-load or unstable conditions. The stability of the current is crucial for DUT testing, so the power supply needs to be carefully chosen and configured to avoid any voltage fluctuations that could impact test outcomes.

The CT is responsible for converting the electrical current from each set of contactors and power supplies into signals that can be more easily monitored and analyzed. The CT transmits current data to the AC power meter and then to the PLC structure shown in Fig. 3. The design of CTs must be highly precise to capture any fluctuations in the current for each set, ensuring that the data is transmitted accurately to the downstream system for further processing. The current controller in this module is responsible for monitoring and adjusting each current group. When an abnormality is detected in the system's current, the controller responds in real time on the basis of pre-set parameters, adjusting the current to prevent equipment damage. This part of the design typically includes multiple protection mechanisms, such as overload protection, overvoltage protection, and overcurrent protection, to ensure that fluctuations in current do not harm the system.

The operation of the entire system relies on the intelligent control of the PLC. The PLC not only collects various parameters but also conducts a comprehensive analysis of the current data, triggering an immediate response if abnormalities are detected. Once the current deviates from the normal range, the PLC will issue an alarm, notifying the operator or automatically activating protective measures to prevent potential equipment failure or safety hazards. In this architecture,

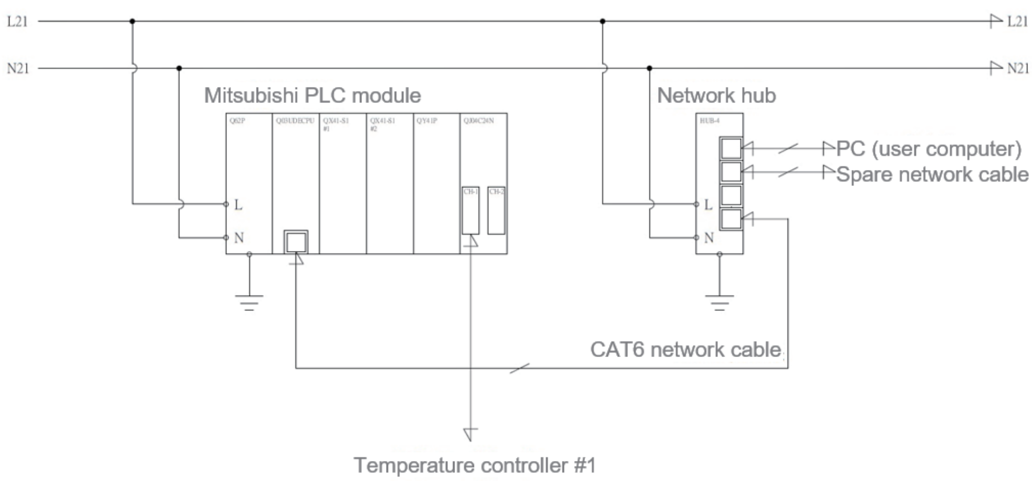


Fig. 3. Architecture of PLC.

real-time response is a critical design requirement. The monitoring of the current and the triggering of abnormal alerts must have a high response speed to ensure that issues can be addressed promptly, preventing further escalation. Moreover, the system must be designed with scalability and fault tolerance in mind, ensuring that additional current monitoring groups can be added without affecting the system's stability. The 10 current monitoring modules forming the burn-in furnace monitoring system enable the precise monitoring and timely adjustment of current, ensuring the safety and stability of the furnace during operation. This monitoring system allows for the quick identification and resolution of any abnormal conditions, ensuring that the equipment remains in optimal operating condition and minimizing the risk of failure.

Figure 4 illustrates the detailed circuit design of the burn-in chamber heating system developed in this study. The design includes several key components and control logic, particularly the two CTs (CT-H1 and CT-H2) used for monitoring the heater's current. These current transformers play a crucial role in continuously monitoring the current flowing through the heater, providing essential feedback signals, and transmitting this data to the system's central control unit—the PLC. On the basis of feedback data, the PLC runs stable control logic to coordinate the operation of the heater and the exhaust system. The PLC's control logic not only precisely adjusts the heater's power output but also automatically modifies the exhaust system's operation intensity on the basis of the heating status. This coordinated operation between the heater and the exhaust system helps prevent equipment failures owing to excessive temperatures, thereby enhancing the overall stability and safety of the burn-in testing system. In traditional burn-in chambers, the lack of precise coordination between the heating and exhaust systems often leads to overheating, energy waste, or ineffective exhaust adjustments, reducing testing

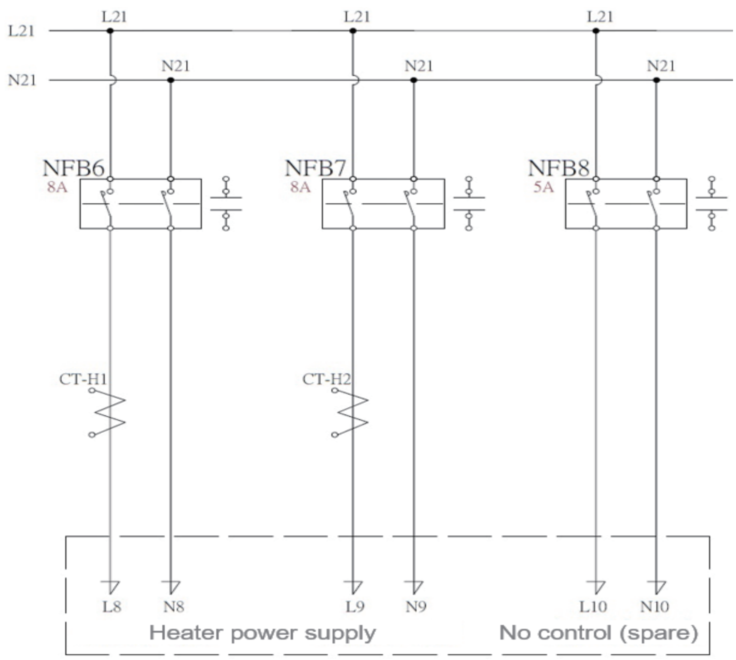


Fig. 4. Heating system circuit design.

efficiency and increasing energy consumption, resulting in unnecessary waste. This system addresses these issues by optimizing the operation through intelligent control strategies, ensuring efficient coordination between the heating and exhaust systems.

The intelligent control strategy dynamically adjusts the operation of the heating and exhaust systems on the basis of real-time measurement data. When the temperature in the testing environment reaches the preset value, the PLC reduces the heater's power output and simultaneously adjusts the exhaust system's airflow speed in response to changes in ambient temperature. This ensures that the indoor environment remains within the optimal range at all times. Such dynamic adjustments effectively prevent overheating or excessive exhaust, maximizing energy efficiency. Additionally, the current monitoring function (CT-H1 and CT-H2) in the system enables the real-time monitoring of the heater's operational status. If any abnormalities (e.g., excessive or insufficient current) are detected, the PLC can promptly adjust the operating parameters or trigger an alarm, further enhancing the safety and reliability of the entire system. This immediate feedback mechanism not only reduces the risk of equipment failure but also helps extend the lifespan of the equipment, thus lowering maintenance costs. The design of this system focuses not only on the coordinated operation of the heating and exhaust systems but also on optimizing energy management through intelligent control and precise monitoring. Compared with traditional burn-in chambers, this design not only improves operational stability but also effectively reduces energy consumption, achieving energy-saving goals that align with modern, eco-friendly, and high-performance equipment standards.

This heat dissipation and temperature control system is designed to achieve precise and stable temperature management, making it ideal for industrial environments that require high-precision control. The core of the system is the temperature control module, which includes key components such as the temperature sensor, temperature controller, heating module, and cooling fan. The temperature sensor continuously measures and transmits the temperature data from the chamber to the PLC, ensuring the real-time feedback of the temperature information. When the system detects that the chamber temperature is below the set range, the PLC triggers the temperature controller to activate the heating module, rapidly raising the internal temperature to the desired level. Conversely, when the temperature exceeds the upper limit, the PLC controls the cooling fan to expel excess heat, preventing the temperature from rising too high and ensuring system stability. The system achieves efficient temperature control primarily through the fan systems shown in Fig. 5 (constant-temperature fan system) and Fig. 6 (exhaust fan system). These two systems work in tandem to create an efficient air circulation system. The constant-temperature fan system is designed to provide uniform airflow, ensuring balanced temperatures inside the chamber and preventing hot spots from forming. The exhaust fan system is responsible for efficiently expelling excess heat, maintaining a cool environment. Both fan systems are precisely controlled by the PLC, with their operation and speed adjustable according to temperature requirements, ensuring optimal ventilation performance.

For the heat dissipation system, this setup utilizes ultrahigh-airflow DC inverter cooling fans, specifically designed to meet both high-efficiency cooling and energy-saving demands. These fans combine advanced DC inverter technology with an optimized fan structure. The DC inverter technology not only enhances the cooling performance but also makes the fan operation

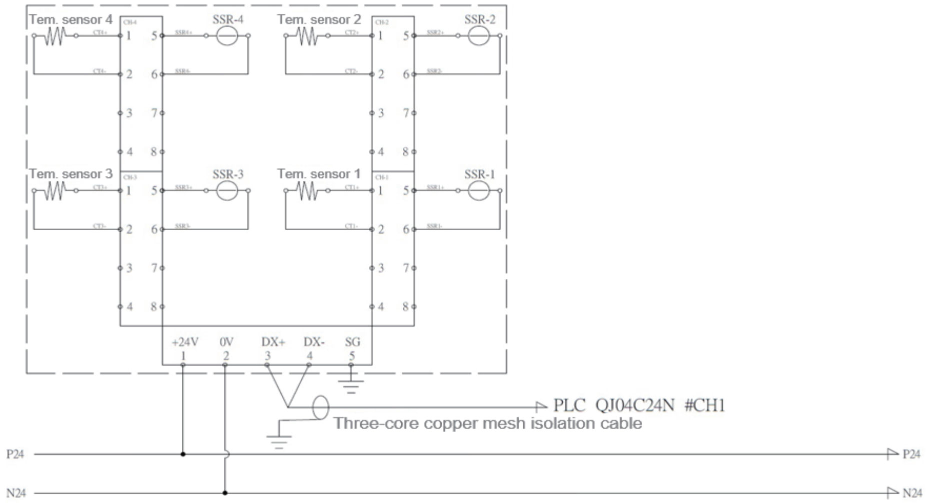


Fig. 5. Circuit diagram of the constant-temperature fan system.

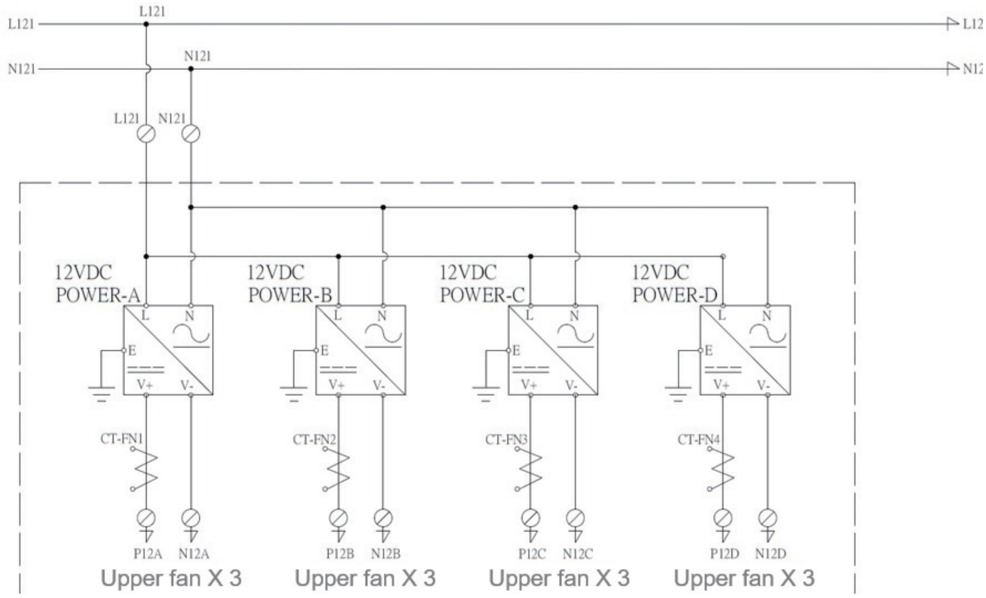
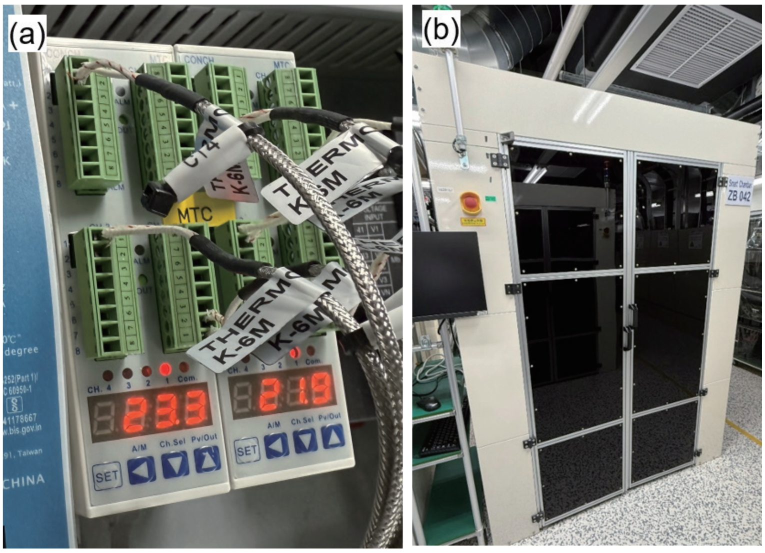


Fig. 6. Circuit diagram of the exhaust fan system.

more flexible, allowing the fan speed to be adjusted according to demand. This capability helps reduce energy consumption by preventing the fan from running at full speed when not necessary, thereby improving overall system efficiency. Additionally, these fans feature intelligent variable frequency control, enabling them to adjust the fan speed on the basis of real-time temperature changes, ensuring that the airflow output always matches the system’s needs. With these efficient temperature control and cooling technologies, the system can maintain a stable temperature range under various operating conditions. Whether under high-load, long-duration operation or rapid start-up and shut-down scenarios, it ensures the precise control and safety of the testing environment, preventing potential risks such as overheating, overcooling, and gas accumulation. As a result, the system not only enhances operational efficiency but also significantly extends the lifespan and safety of the equipment, meeting the high demands for stability, precision, and energy efficiency in modern industrial applications.

The four-channel temperature control module and the actual appearance of the burn-in chamber developed in this study are presented in Figs. 7(a) and 7(b), respectively. During this testing process, we conducted a temperature stability test on the furnace equipped with a monitoring system. The ambient temperature at the test site was 25 °C, and the total duration of the test was 30 min. The goal of the test was to gradually increase the furnace's internal temperature from 41 to 48 °C and maintain stable temperature control within this range. To ensure the accuracy of the test, we simultaneously compared the temperature set by the PLC system with the actual temperature measurements taken on-site. Figure 8 shows the measured temperature during the temperature stability test. From the graph, it can be observed that both the actual measured temperature and the PLC-set temperature are in close agreement, with a deviation within 1 °C. This demonstrates that the furnace system we designed and manufactured offers extremely high temperature control accuracy and stability, making it highly effective in environments where precise control is required. Additionally, throughout the entire testing process, the temperature control system responded promptly, ensuring that the furnace quickly reached and maintained the set target temperature range, whether during the heating phase or while stabilizing the temperature. This reflects the outstanding performance of the equipment in precise and controlled environments.



(a) (b)

Fig. 7. (Color online) (a) Four-channel temperature control module and (b) actual appearance of the burn-in chamber.

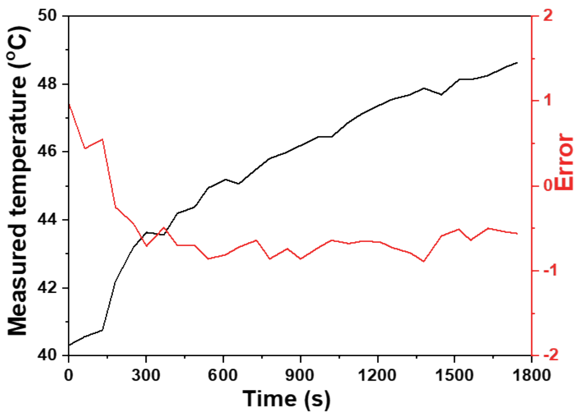


Fig. 8. (Color online) Temperature recorded by the temperature tester during the heating test and the error values when compared with the PLC data at the same time.

4. Conclusions

In this study, we primarily focused on designing a burn-in furnace system with a PLC as the core control unit. The system continuously monitored the temperature inside the chamber through temperature sensors and coordinated the operation of the heater and exhaust fan to maintain a stable environment. This design ensured effective heat dissipation and precise temperature control, forming a comprehensive thermal management system with an integrated monitoring system. The current monitoring module in this system consisted of 17 CTs connected to the monitoring unit. These included 10 CTs (CT-1R to CT-10R) for monitoring the current of the DUTs, 2 CTs (CT-H1 and CT-H2) for monitoring the current of the heater, and 5 CTs (CT-FN1 to CT-FN5) for tracking the currents of the exhaust and temperature control fans. This detailed monitoring setup ensured that the system maintains optimal performance, with constant real-time data tracking for precise control over each component. The goal of the test was to gradually increase the furnace's internal temperature from 41 to 48 °C. The measured results showed that both the actual measured temperature and the PLC-set temperature were in close agreement, with a deviation within 1 °C.

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References

1 https://www.istgroup.com/en/burn-in-testing/ (accessed June 2024).
2 https://www.keysight.com/us/en/assets/7018-06658/white-papers/5992–4051.pdf (accessed September 2024).
3 C. L. Wu and C. T. Su: Reliab. Eng. Syst. Saf. **76** (2002) 53.
4 https://www.intechopen.com/chapters/55859 (accessed December 2017).

5 F. Almeida, P. Bernardi, D. Calabrese, M. Restifo, F. Almeida, P. Bernardi, D. Calabrese, M. Restifo, M. Sonza Reorda, D. Appello, G. Pollaccia, V. Tancorre, R. Ugioli, and G. Zoppi: 2019 IEEE 22nd Int. Symp. Design and Diagnostics of Electronic Circuits & Systems (DDECS, 2019) 1–6.
6 Y. H. Ng, Y. H. Low, and S. Demidenko: 2008 IEEE Instrumentation and Measurement Technology Conf. (2008) 1685–1689.
7 N. Kim and W. Jung: Eur. J. Oper. Res. **146** (2003) 433.
8 S. Kumar and R. Patel: Int. J. Adv. Res. Eng. Technol. **8** (2017) 45.
9 H. H. Aung and T. Z. Thein: Int. J. Trend Sci. Res. Dev. **3** (2019) 1644.
10 Y. Duan, H. Ji, X. Sun, W. Tian, and H. Cui: 2022 23rd Int. Conf. Electronic Packaging Technology (ICEPT, 2022) 1–6.