The research on Power Supply Array Intelligent Management Technology for Spacecraft Thermal Test

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Abstract. The thermal test of spacecraft has a large demand for the program-controlled power supply, which was configured as array. In this paper, the intelligent management technology of program-controlled power supply is researched. Base on the analysis of the history fault type of power supply, the fault detection technology of power supply is studied. Then, combined with the technology of power supply redundancy switching, an on-line switching device is designed. Through the verification experimental, the experimental results show that the system can quickly realize the detection and positioning of the fault power supply, and can finish the online switching of the fault power supply to the backup power within the second-level time. The research of intelligent management technology enhances the management efficiency of the large scale power supply array, and improves the operational reliability of the spacecraft thermal test.

1. Introduction
As the longest, most expensive and most complex test project in the development process of spacecraft, the reliability requirement of spacecraft vacuum thermal environment test is very strict. With the rapid development of space technology, the design scale and technology state of spacecraft are more complex, and then, the scale and technical requirements of thermal test equipment are also increasing[1]. As a subsystem of the environment simulation equipment’s measurement and control system, the temperature control system is mainly composed of control software, program-controlled power supply and heating device. The power supply provides power for heating device, which include infrared lamp, infrared cage and thin film heater. The radiation heat flow value of the heating device is controlled by the output current of the power supply. Therefore, the power supply is one of the most critical instruments for the spacecraft thermal test[2]. Because of the large scale power supply, especially for the spaceship, space station or other large spacecraft, the number of power supply will reach hundreds. At the same time, the operation of the power supply is more complex, and the communication frequency with the temperature control software is relatively large. Therefore, the power supply often occurs fault phenomena such as large output error, no output or communication interruption, which will cause the abnormal test state. At present, the level of power supply fault detection is low. After finding the power supply fault, it can only be replaced by the normal power supply through artificial operation. This method has a long time consuming, low efficiency and easy to cause quality accident, which greatly affects the reliability of spacecraft thermal test.

In order to solve the above problems, it is necessary to study the intelligent management technology of the program controlled power supply for the temperature control system of spacecraft thermal test. In this paper, Agilent N5750 power is used as the research object. Firstly, combining the fault case which happened in the history thermal tests, the fault type of the power supply is
summarized. The real-time detection technology of power supply fault modes which includes power output overload, no output, communication packet loss and interruption are studied. Then, based on the redundancy switching technology, the online switching device which realizes the switch between the fault power supply and backup power is designed. Finally, the intelligent management system for power supply array is developed. The system can complete the fault detection and online switching of up to 30 power supply in 3 seconds, and the detection rate can reach more than 98%.

2. Research of power supply fault detection technology

2.1. Analysis of power supply fault type

According to the analysis of power supply fault information in the decades history of spacecraft thermal test, the power supply fault types can be divided into output state fault and network state fault\(^3^\)-\(^4^\). The fault tree is showed in the Figure 1.

![Fault Tree](image)

Figure 1. The fault tree of power supply occurred in spacecraft thermal test.

The output state fault includes output overproof and working fault. When the internal circuit of power supply fails, the difference between the actual value of output current (voltage) and the ideal value of output current (voltage) exceeds the maximum tolerance error of the test. The above kind of power supply fault is defined as the output overproof. When the power supply is damaged due to bad working environment, long times working and internal circuit failures, it will shutoff output and the power supply fault is defined as the working fault.

The network state fault includes communication interruption and poor communication. Due to the fault of power supply communication module, the router fault, cable fault or the LAN interface plug is not in place, the control software can’t communicate with the programmable power supply well or the rate of packet loss is large.

2.2. Design of power supply fault detection scheme

Through the research of the power datasheet, it can be reached that the power supply fault mode can be detected by measuring the relevant port signals of the interface J1 on the rear panel.

![Detection Scheme](image)

Figure 2. The schematic diagram of power supply output state fault detection.

The power supply actual output current is an important monitoring parameter in the spacecraft thermal test. The analog output value (0-10VDC) of the current output monitor port P24 in interface J1 is proportional to actual output current (0-4ADC). Therefore, the power actual output current value can be obtained by measure the port P24 in interface J1. The difference between the actual output value and the target output value of power supply is compared with the output error threshold value. The threshold value is 0.1A generally. The results will be used to decide whether the power supply
output has the output overproof fault. As to the power supply working fault, the working fault signal can be obtained by measure the port P16 in interface J1. The output form of port P16 is TTL signal. When the output level of the P16 port is high, the power supply is working normal. Otherwise, the power supply is working fault.

In the control system of spacecraft thermal test, all the power supply communicate with the server and client by the LAN switch. In order to realize the the network state fault detection, the ICMP communication protocol technology is applied in this paper[5]. The system host sends the data packets to the IP address of the detected power continuously and analysis its difference to the returned data packets. It also determines whether the host receives the returned packet in the set waiting time. In every period of network state detection cycle, if the host can't received the returned data packets continuously and exceed the maximum allowable continuous number (e.g. 5 times), the detection process will be terminated and the fault style will be judged as communication interruption. If the loss rate of returned data packets exceeds the maximum allowable packet loss rate, the detection process will be terminated and the fault style will be judged as poor communication.

3. Research of power supply redundancy switching strategy
In order to achieve the online and rapid replacement of the fault power in the spacecraft thermal test process, and reduce the risk brought to the thermal test due to the manual replacement operation, the power supply redundancy switching technology was researched[6]. Base on the relay network technology, an online switching device for power supply is developed, and the power supply online switching strategy is designed. The online switching scheme is shown in the Figure 3.

As shown in Figure 3, the main design idea is that connect the 30 main power supplies output channels and 2 backup power supplies output channels to the relay network input channels, and then connect the 30 power supplies output channels of the relay network to the external heat flow simulation device. Among them, the design of logic combination is the key content in the design of relay network[7]. The relay network consists of 120 single-pole double-throw(SPDT) relays. Each of the 4 SPDT relay constitutes an electrical connection unit. Each electrical connection unit corresponds to the external heat flow simulator device’s input channel and its corresponding main power supply output channel, and 2 backup power supplies output channel. The electrical connection unit can arbitrarily matching connection the external heat flow simulation with the corresponding main power supply or one of the two backup power supplies. The working principle of each electrical connection unit is shown in Figure 4.

As shown in Figure 4, the state of each relay in the electrical connection unit is normally closed, and the input channel A of the external heat flow simulator device is connected to the main power output channel B under the default state. According to the combination of relay state shown in Table 1,
the input channel A can be switched to the output channel of the backup power 1 or the backup power 2.

Table 1. Corresponding relation table of relay state and load supply channel

| Relay name               | Corresponding power supply |
|-------------------------|---------------------------|
| Main power supply       | S00 0 S01 0 S02 - S03 -  |
| Backup 1 power supply   | S00 1 S01 0 S02 1 S03 0  |
| Backup 2 power supply   | S00 1 S01 1 S02 1 S03 1  |

4. Design of power supply intelligent management system

4.1. The overall design of system scheme

Based on the research of power supply fault detection and online switching technology, this paper develops a power supply intelligent management system and realizes the intelligent management of a power cabinet which contains 30 power supplies. This system consists of hardware and software. The hardware system consists of main control subsystem, power output state detection subsystem, network state detection subsystem, and online switching subsystem. The overall structure of the system is shown in Figure 5.

![Figure 5. The schematic diagram of the system overall structure.](image)

4.2. The design of hardware system

The main control subsystem of hardware system adopts the combination of the PXI JX5010 industrial control chassis and the PXI/CPCI5098 embedded host controller. It can realize the control of instrument resources based on the PXI bus[8].

The output state detection subsystem is used for detecting the output overproof and working fault of the 30 main power supplies and 2 backup power supplies. The network status detection subsystem is based on the LAN switch and implements the detection of the network status of 32 power supplies through the ICMP software protocol and its derived algorithms.

The online switching subsystem mainly realizes the functions of power redundancy switching and local enable output control. According to the research described in section 3, a online switching device is developed. The device consists of 10 Pickering 40-161-101 high-power switch modules. The switch module is PXI bus mode, and can be integrated in the industrial control chassis. Each switch module has 12 SPDT relays, and its signal channel max switch current is 10A which is more than the max output current of researched power supply. As shown in Figure 6, the relay network can constitutes 30 electrical connection units and realize the logic combination between 30 main power supplies, 2 backup power supplies and 30 external heat flow simulation device.
Besides, when the power supply’s network state failure, it can’t be shut down output by the remote command. In order to ensure the cold switching, in this paper, the power supply local output control function is realized by the control of relay which connected the port P1 and P14 in the interface J1.

The hardware system is designed as cabinet form, and the hardware resources of each subsystem are integrated inside the cabinet. It is easy to move and use in the laboratory. The appearance of the cabinet is shown in Figure 7.

4.3. The design of software system

The software system is developed on the basis of the VS2010 environment, and selects VB as the development language. The software database uses Microsoft SQL SERVER 2005 and calls the Agilent I/O library to realize the underlying driver of the power supply.

The software system adopts C/S architecture mode, and consists of the main control software and the display software. Among them, the main control software runs on the main control subsystem of the hardware system. It can receive the instructions of the display software in real time, communicate with the system hardware resources directly, and send the latest detection data information to the display software for interface display. The display software runs on any client in the LAN of spacecraft thermal test measurement and control system. It receives and displays the newest detection data from the main control software. At the same time, it receives the input information from the human-machine interaction interface and sends control instructions to the main control software. The main control software communicates with the display software by the UDP protocol.

The software was designed and developed by the idea of modular. It has a strong maintainability, extendibility and can provide various configuration interfaces. The structure of the software is shown in Figure 8.
5. Test verification and result analysis

After the realization of the array power supply intelligent management system, the performance verification test was carried out in CAST spacecraft thermal test laboratory. According to the system design index, the test results about the detection accuracy of power supply output current, detection rate of output state fault and network status fault, and the reliability of online switching function are verified and analysed.

As shown in Figure 9, the managed 30 power supplies is configured in an cabinet. The output of the power supply cabinet is connected to the input channel interfaces B1 and B2 of the power supply management system through two cables. Then, the output interfaces A1 and A2 of the power supply management system are connected to the infrared lamp array selected as load for this test. The cable CK1~CK4 are used to connect the JI port signal of each power supply interface.

![Infrared lamp array](image)

**Figure 9. The working status electrical connection diagram of power supply management system**

In order to verify and analyse the detection accuracy of power supply output current, the method of the simulated working condition test is adopted. All of the 30 power supplies use the same simulated working condition. The power supplies are controlled by flux control software. As shown in Figure 11, the cycle of loaded condition current is 5min, and the single step is 30s.

After the test, the result of 5th, 10th, 15th and 20th power supply are selected, and the different between the detected output current by system and the loaded output current are shown in Figure 12.

![Current diagram](image)

**Figure 11. The current diagram of simulated working condition.**

![Detection error curve](image)

**Figure 12. The detection error curve of power output current by the management system.**

Firstly, we can see in the Figure 12 that the absolute error between the detected output current and the loaded output current is less than 0.02A, which is in the range of output error threshold value 0.1A. The relative error of the system is less than 0.5%, which meet the demand for output overproof detection.

In order to verify the detection rate of output state fault and network status fault, and the reliability of online switching function, the method which includes manual adjust the output current of the power supply in local and the network cable status are adopted. Through the 100 times repeating of the above operation, we can conclude in the detecting result that the system can identify and locate the output and network faults effectively, and the correct rate of detection is 100%.
At the same time, the online switch is also tested. The verification results show that the system switching logic is correct and no sparks phenomenon in the switching process. It can effectively implement that the fault power is replaced by backup power in the time less than 2 seconds.

Acknowledgements
In this paper, the power supply fault detection technology and redundancy switching technology are researched, and the intelligent management system of array power supply is developed. The system realizes the real-time monitoring of the output state and network state of 30 power scale supplies. The output of 2 backup power supplies can replace any fault power supply by the online switching device. The minimum period of fault detection is 3s, and the switching times of power supply is less than 2s. The application of this system improves the efficiency of identify and location of failure power, reduces the replacement time of the failure power, and improves the reliability of the spacecraft thermal test greatly.

References
[1] LIU C, WANY Y R. 2010. The software architecture design of measurement and control system in vacuum thermal tests[J]. Spacecraft Environment Engineering.
[2] SUN R M, LIU W Y, ZHANG R C, et al. Design of Distributed Measurement and Control System for Spacecraft Thermal Vacuum Test[J]. Computer Measurement & Control.
[3] MA L, WANG H J. 2013. Fault diagnosis method based on output voltage and supply current collaborative analysis[J]. Chinese Journal of Scientific Instrument.
[4] CAO W B, CHEN G S, NIU G, et al. 2014. Monitoring technology of network devices based on ICMP and SNMP[J]. Computer Engineering and Design.
[5] XIAO Y D. 2013. Packer loss detection algorithm and key points of its implementation in network status monitor[D]. Chengdu: University of Electronic Science and Technology of China.
[6] REN Z J. 2016. Research of Switching Methods on Seamless Power Supply for Important Loads[D]. Chongqing: Chongqing University.
[7] YING C L, CAI X, WANG C C. 2011. The Study of Self-test for Matrix Switch of ATS[J]. Journal of Astronautic Metrology and Measurement.
[8] ZHU H F, YANG G. 2013. Intelligent Test System Design Based on PXI Bus Module[J]. Computer Measurement & Control.