Design and Implementation of a Test System for the Simulation Experiment of the Space Reactor

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Abstract. With the increasingly mature development of China’s deep-space nuclear power technology, it is necessary to formulate a special nuclear reactor ground test application system. In response to the requirements of comprehensive functional testing of space nuclear reactor systems, a design method for a space reactor simulation experiment test system is proposed, designed and implemented a special comprehensive experimental test system suitable for the automatic control system of the space reactor is developed. The space reactor simulation experiment system has been verified by several comprehensive joint test experiments. It has a high degree of automation, simple operation, user-friendly interface, and easy maintenance. The implement of this system provides a reference for China's future space nuclear reactor system ground test application and experimental verification research.

1. Introduction

With the increasingly mature research and development of China’s deep-space nuclear power technology, the research and application of nuclear-powered spacecraft ground testing and verification systems have been put on the agenda. In view of the high safety and high reliability of space nuclear reactor systems, and the require special environmental tests for nuclear reactor function and safety, it is necessary to develop the Special comprehensive test and test environmental conditions for space nuclear reactor systems, special consideration of nuclear reactor function and safety requirements require special environmental tests and special tests. Therefore, this paper designs the Simulation Experiment of the space nuclear reactor. Therefore, this paper designs the simulation experiment of the space nuclear reactor.

The master control system of the space nuclear reactor is composed of a reactor control computer, a data acquisition and small component centralized control function module, a control drum and safety rod drive mechanism control function module, and an electromagnetic pump control drive function module. The main controller system of the space reactor is used to simulate the operation control of the space nuclear reactor system, and can realize the functions of reactor control, sensor signal acquisition and processing control, control drum and safety rod drive mechanism control, and reactor power supply system control.

The simulation experiment test system of space nuclear reactor master control system is a special comprehensive function test for the automatic control system of space nuclear reactor. It is mainly used for the system joint debugging and joint test of the ground simulator during the space nuclear reactor system integration process, the system function test, and the power supply control of the space nuclear reactor and the half-physical simulation test of the space nuclear reactor. The system verify
whether the space nuclear reactor system design meets the requirements and whether the performance meets the standard. The successful development of the system provides a reference for the China’s future research of space nuclear reactor ground application system and test verification.

2. Introduction of the test system
This is the connection relationship between the simulation experiment test system and the functional modules of space nuclear reactor master control system, as shown in Figure 1.

Figure 1. Connection diagram of the system and the master control system
The dashed frame represents the simulation experiment test system of the space nuclear reactor. And the system hardware test board and the DC power supply module are stacked in a standard cabinet. The test system performs the data transmission control with the master control system through 1553B bus, Ethernet and serial communication.

This is the functional block diagram between the simulation experiment test system and the master control system. And the main functions of the test system are as follows.

2.1. The function test of the master control system
The single function test of the master control system includes function test of each signal input channel, function test of each signal output channel, 1553B bus communication function test (including BC and RT), control function test of the drive mechanism (control drum drive mechanism and safety rod drive mechanism) and the electromagnetic pump, etc.

2.2. The control function test of the nuclear reactor
The control function test of the nuclear reactor realizes the half-physical simulation test of the space nuclear reactor control function by the master control system. The half-physical simulation test mainly includes the single-machine control and test of the control drum and safety drive mechanism and the reactor electromagnetic pump, and real-time monitoring and command control of the operating status of the entire space reactor master control system.

2.3. The animation demonstration of the master control system
The animation demonstrations include reactor 3D model animation demonstration, control drum and safety rod drive mechanism action demonstration, electromagnetic pump flow model animation
demonstration, virtual instrument, virtual indicator, command window, dynamic characteristic curve, etc.

2.4. The simulation function test of the master control system
The function includes the test of command response action and response time, data reporting function, remote control function (start, shutdown, and cut, etc), control drum and safety rod drive mechanism action command and electromagnetic pump action command, etc.

2.5. The simulation power management of the master control system
Simulate the master control system's general power grid on/off function, sensor power control function, reactor power supply and electric power adjustment function, control drum and safety rod module power control function, electromagnetic pump module power management control function, and data acquisition and small component centralized control function module power management control functions, etc.

2.6. Drive mechanism model
Establish safety rod drive mechanism and 3 control drum drive mechanism models. The test software controls the operation of the safety rod drive mechanism and control drum drive mechanism through command signals. At the same time, the test software interface dynamically displays the current operating status of the drive mechanism model, including rotation Angular displacement, rotational angular velocity, on/off status of electromagnetic clutch and electromagnetic lock, motor status, etc.

3. System hardware design
The hardware structure of the space reactor master control simulation experiment test system, as shown in Figure 2. Due to the complex functions by the test system and a wide variety of control signals, acquisition signals and output signals, the hardware structure of the test system is divided into 7 functional modules: master control module, programmable power supply, PXI acquisition box, acquisition module, output module, serial communication module and junction box.

3.1. Master control module
The master control module uses Taiwan's Advantech industrial control computer as the core of the test system. The industrial control computer is equipped with a 1553B bus communication board, Ethernet card, etc, which is used to provide an integrated software development environment, runs system management software, data management software, test programs, and reactor control computer simulation programs, and achieves task management, data processing, and documentation storage and command sending and receiving etc, and is equipped with 4 high-definition monitors to display the user interface of the test system software.
3.2. Programmable power supply
Programmable power supply, using the PSW program-controlled power supply of GW Instek, is used for power management of the test system, achieve the power supply for a reactor control computer, a data acquisition and small component centralized control function module, a control drum and safety rod drive mechanism control function module, an electromagnetic pump control drive function module and a test System.

The industrial control computer is connected to the programmable power supply via Ethernet to realize the control of the rated output voltage and current, the output protection voltage and current, the control of parameters and the status detection for the programmable power supply.

3.3. PXI acquisition box
PXI acquisition box, select NI PXIe-8840 controller. PXIe-8840 is a high-performance embedded controller based on Intel Core i5-4400E processor, suitable for PXI Express system. The controller has a 2.7 GHz base frequency, a 3.3 GHz dual-core processor, and a single-channel 1600 MHz DDR3 memory, making it ideal for processor-intensive modular instrumentation and data acquisition applications. The PXIe controller provides the LabVIEW Real-Time operating system, which is used to complete the acquisition of analog quantities, the output of analog quantities, the acquisition of switching values, the output of switching values, and the acquisition of OC commands, the output of OC commands etc, which can greatly shorten the test time.

3.4. Acquisition module
The acquisition module realizes the acquisition of analog, OC signals and switches of the test system, including 32-channel analog of a reactor control computer, 64-channel analog of a data acquisition and small component centralized control function module, the angular position of a control drum and safety rod, the voltage and current value of the electromagnetic clutch and electromagnetic lock, and the motor temperature, and the 64-channel OC signals, 64-channel switches of a data acquisition and small component centralized control function module, and the program control, OC signals and 32-channel switches of a reactor control computer, etc.

3.5. Output module
The output module realizes the output of the analog, control command and switches of the test system, including 96-channel analog, OC signals, command signals and switches of the test system.

3.6. Serial communication
Serial communication, using RS-422 standard half-duplex I/O, 115.2Kbps of asynchronous communication rate, realizes the communication between the test system and a reactor control computer A, a reactor control computer B, a reactor control computer C by command and data flows.

3.7. Junction box
The signal junction box is used for test signal conditioning, isolation box interface conversion, and provides power switch and display status of the test system.

4. System software design
According to the technical requirements and functional characteristics of the space nuclear reactor main control computer simulation experiment test system, the software function is divided into five functional modules, including human-computer interaction module, measurement control module, data acquisition module and data processing and management module. And the software is divided into PXI control software running in Real-time OS environment and master control software running on industrial computer. This is software composition diagram of simulation experiment test system, as shown in Figure 3.
4.1. PXI control software
The PXI control software runs in the real-time operating system environment in the PXI acquisition box provided by NI. It is responsible for completing the data acquisition module function of the simulated experimental test system, realizing the data acquisition of the test system, UDP data grouping and system command analysis, and transmitting a standardized data collection stream to the industrial control computer via Ethernet.

The PXI control software is programmed by LabVIEW RT. LabVIEW RT is a real-time extension for LabVIEW programs. It provides a new graphical programming solution for creating independent embedded systems. It is used to develop and debug graphical deterministic real-time applications, and develop and debug graphically deterministic real-time applications under non-real-time systems. Debug the application and load it to the Real-time platform via Ethernet to run.

4.2. Master control software
The master control software is programmed in C# language and runs in the windows operating system environment provided by the industrial control computer. It is responsible for the completion of human-computer interaction functions, measurement control functions, and data analysis and management module functions. The functional block diagram of the master control software is shown in Figure 4.

4.2.1. Reactor status
The reactor status module realizes the visualization of reactor core parameters, such as reactor power, reactor startup time, reactor fault information, reactor bus current, bus voltage, anti-reactor period, NaK temperature, reactor inlet and outlet temperature, and control drum and safety rod angular position.
4.2.2 Reactor control
The reactor control module realizes the operation control and status detection of the master system, including the operation control of the control drum and safety rod drive mechanism, the electrical measurement pump module and the data acquisition and processing module, and detecting the operation status of the equipment, which is displayed on the reactor 3D model and dynamic display interface in real-time.

4.2.3 Measurement control
The system measurement control module realizes the communication control between the industrial computer and the PXI box. The industrial control computer sends the control command to the PXI box via Ethernet, and the PXI box receives the control command, and sends the corresponding collected data stream to the industrial control computer for analysis and processing, and displaying the collected parameter values in the corresponding animation display window in real-time.

4.2.4 Configuration management
The system configuration control module realizes the parameter configuration of the master system, including the configuration operation of the command content such as start-up, shutdown, switching, reset, and the configuration of key display parameters, such as the bus current and voltage of the reactor, and the electromagnetic flow rate of the pump, the temperature of the reactor, the angle of the control drum, the insertion and withdrawal status of the safety rod.

4.2.5 Data management
The system management module includes data storage, data reading and data playback functions. The data storage function stores data logs generated during system operation, such as configuration files, log records, and important parameter values, in the database. The data reading function reads the data logs and important parameter values generated during a certain period of time from the database according to the constraints entered by the user. Data playback enables users to review the log records and key parameter values generated during a certain period of time during system operation, and is used to find and analyse problems when the system fails.

5. System implementation and verification
The hardware construction of the space reactor master control simulation experiment test system is shown in Figure 5, and the test system software is shown in Figure 6.

![Figure 5. Hardware structure diagram](image1)

![Figure 6. Test system software](image2)
The experimental results show that the simulation experiment system software is very good to complete the reactor 3D animation model display, control drum and safety rod drive mechanism model display, electromagnetic pump flow model display, and successfully simulate the master control system power management, data collection and small parts concentration Module acquisition, output control, control drum and safety rod drive mechanism operation control, electromagnetic pump flow control and reactor control computer command control and other simulation tasks. The simulation experiment test system runs well and meets the design requirements of the space nuclear reactor master control system.

6. Conclusion

In response to the requirements of comprehensive functional testing of space nuclear reactor ground simulators, a simulation experiment test system suitable for the space reactor master control system was designed and implemented. This paper introduces in detail the composition of the simulation experiment test system, the function of the system and the design of the system's software and hardware. The simulation experiment test system has been verified by multiple joint test experiments. It has a high degree of automation, simple operation, friendly user interface, easy maintenance, and good use effect. It provides reference for the development and test verification of the space nuclear reactor ground test application system.

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