Design of Equivalent Simulation Test System for Universal Power Supply and Distribution of Space Station Multi-aircraft

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Abstract. In the process of system-level test and verification of manned spacecraft, traditional power supply and distribution interface test and verification usually use a dedicated equivalent simulation system for special aircraft. The system state is solidified, the simulation method is single, the function is simple, and it cannot be adapted to the subsequent multi-model and extended functions verification. Aiming at the needs of power supply and distribution interface test verification in the current multi-cabin and multi-aircraft system-level test process of space station engineering, a universal, multi-spectrum-supported, and expandable multi-aircraft power supply and distribution equivalent simulation test system is proposed. The system adopts a modular design, combined with a reconfigurable software system, and deeply integrates software and hardware. Through a reconfigurable design, it has the ability to support the interface verification between multiple different aircraft, and it can quickly perform the new research aircraft on the ground. Effective verification. Established a general-purpose module combining software and hardware, with more comprehensive coverage (signal, power, step), higher automation, more detailed data recording, and verified by model testing, the system can quickly realize the interface with multiple types of manned spacecraft Simulation verification improves the parallelism of test and development, covers more failure modes, the system structure is reliable, and the cost is significantly reduced.

Keywords: Space station · General purpose · Equivalent simulation

1 Introduction

With the implementation of the third step of the manned spaceflight project, in the future construction stage of the space station, the number of launches of various manned spacecraft such as various sections of the space station, manned spacecraft, and cargo spacecraft will increase sharply. It has become the norm. The development cycle and test cycle of the spacecraft will gradually shorten, and the mission function of the spacecraft will gradually expand. Therefore, the functional coverage, adaptability, generalization, long life, research and development of the power supply and distribution test equipment

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required for spacecraft testing will be Efficiency and other aspects have put forward higher requirements.

The spacecraft equivalent simulation system is an equivalent simulation device that simulates the electrical performance of the spacecraft through the circuit and the instrument system, such as regulated power supply, ground telemetry, pyrotechnic access, and hard-wired command execution [1]. It can realize the effective simulation of spacecraft energy system, power distribution system and some information systems. Generally, the power supply load, downlink analog quantity, state quantity and pyrotechnic command of the aircraft are simulated before the electrical performance test of the spacecraft, and at the same time, the uplink control signal of the ground equipment is received, and the uplink and downlink paths are checked, so as to verify the state quantity measurement loop of the aircraft and the ground equipment., the correctness of the analog measurement loop, the command control loop, and the correctness of the function of the ground equipment.

The current equivalent simulation systems are dedicated to each model, and are used to simulate the aircraft power supply load, downlink analog quantity, state quantity, and pyrotechnic commands, and at the same time receive ground equipment control signals for path detection [2]. The common problem of the interface verification test system between traditional manned spacecraft is that it is difficult for ordinary users to change its relatively fixed functions after the construction is completed, and the special plane is dedicated, which cannot meet the diversity test. The developed test system matches the interface of a single type of aircraft, is incompatible with each other, has poor scalability, lacks generalization and modularity, and cannot share software and hardware components, which not only reduces the development efficiency, but also improve complex test system expensive. The traditional power supply and distribution simulator mainly completes the matching check of the static interface, lacks modeling and simulation of the dynamic process of the aircraft power supply and distribution system, and cannot analyze and evaluate the interface characteristics at the same time as the equivalent simulation.

This paper proposes an equivalent simulation system for manned spacecraft based on general modularization. This system can be applied to the multi-type spectrum testing requirements of manned spacecraft in space station engineering. Modeling the multi-type spectrum of human and spacecraft, fully integrating software and hardware to improve the dynamic equivalent simulation performance, with the ability to analyze interface characteristics, to complete the full test of the power supply and distribution test system, and to evaluate the dynamic performance and indicators of the system, which can effectively reduce the time cost brought by equipment development, and this set of system equipment is more modular and generalized, which is convenient for equipment maintenance and replacement; the equipment is miniaturized and has a higher degree of integration.

2 Equivalent Analog System Design

As an important part of the ground power supply and distribution test system, the spacecraft equivalent simulation system [3] is generally dedicated to the model, and is managed as the special equipment of the model. At present, there is research on the degree of automation of the equivalent simulation system of the spacecraft, but there is less research on the generalization of the equivalent simulation system, and less research on the dynamic characteristics of the simulated object for the equivalent simulation system. Insufficient. Improving the repetition rate, dynamic simulation performance and signal analysis capability of the equivalent analog system can effectively improve the test efficiency of the model.

Using general reconfigurable design ideas and modular design methods to design the system, its hardware modules or (and) software modules can reconfigure (or reset) the structure and algorithm according to the changing data flow or control flow [4]. In a reconfigurable system, hardware information (configuration information of programmable devices) can also be dynamically invoked or modified like software programs. This not only retains the performance of hardware computing, but also has the flexibility of software.

The general power supply and distribution equivalent simulation system has the following technical characteristics:

1) Ability to efficiently implement specific functions. Reconfigurable logic devices are all hardwired logic, which changes the function by changing the configuration of the device.
2) The device configuration can be dynamically changed to flexibly meet the needs of various functions.
3) The system cost can be greatly reduced. In addition, for functions that will not be used at the same time, consider using dynamic reconfiguration technology to implement them separately in different demand periods, so as to achieve "multiple uses for one machine", saving resources, space and costs. A typical reconfigurable, modular test system composition is shown in Fig. 1.

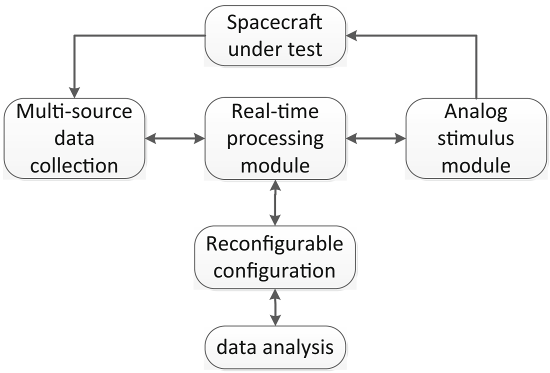

Fig. 1. Reconfigurable and modular test system composition

2.1 Modeling of General Power Supply and Distribution Equivalent Simulation System

Through the analysis of the static technical state and dynamic process characteristics of hardware interfaces such as load characteristics, hard-wire commands, state telemetry, and pyrotechnic actions during the in-orbit flight of multiple manned vehicles in the space station. Although the power supply voltage system, load attribute and power, signal path definition, telemetry definition, and signal characteristics are different for each aircraft, by summarizing and analyzing the interface circuit, signal logic, and signal waveform of each aircraft, it is possible to identify the power supply for each aircraft. The general key elements of the power distribution equivalent simulation are analyzed and designed to form a general equivalent simulation system model. The model includes all elements of the test and verification of the power supply and distribution interface of the existing space station aircraft. Based on the model, forward design can be carried out to match the aircraft-to-ground interface, and then the design and configuration status of the equivalent simulation system can be determined in one step.

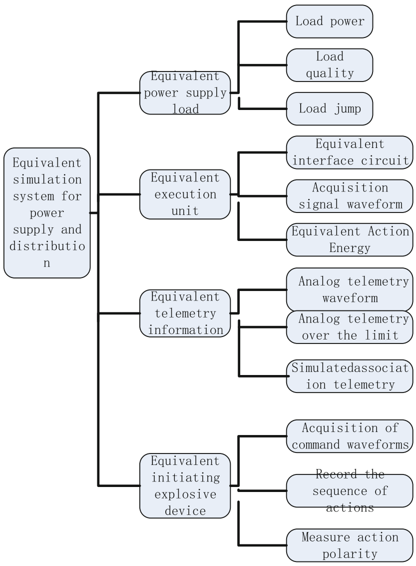

Fig. 2. Power supply and distribution equivalent simulation system model

2.2 Equivalent System Hardware Design

Through the analysis of the equivalent simulation system model, the hardware composition of the equivalent system is modularly designed, and a single module is designed universally. Each module adopts a common standard interface, which is easy to replace and expand. The equivalent simulation system is based on the universal design. In the above, the overall system has been modularized. The overall system adopts the mode of motherboard + functional daughter board, and has carried out a universal design for the interface characteristics of the spacecraft's multi-type spectrum, and has the ability to expand functions. The equivalent simulation system based on modular instruments consists of six parts: control unit, general power supply and load module, jumper box, conditioning box, pull-out display, and cabinet. The system integration diagram is shown in Fig. 3.

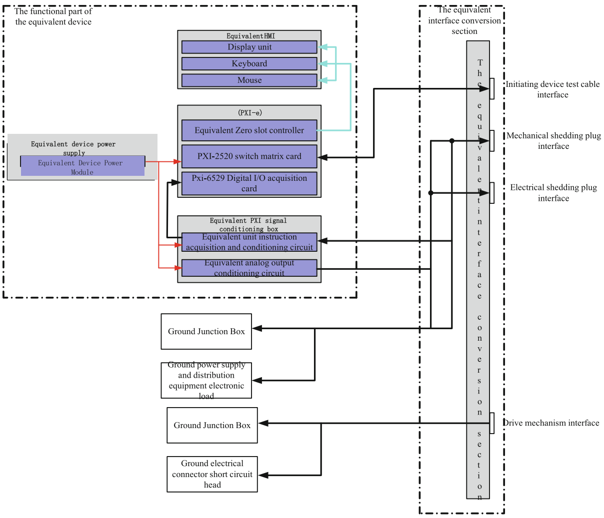

Fig. 3. Schematic diagram of equivalent device system architecture

In order to meet the verification requirements of various scenarios, the control unit is configured in the maximum modular way, and the board configuration can be flexibly adjusted according to the task requirements, so as to realize the expansion of system functions such as analog quantity, state quantity and open command., has the technical characteristics of high integration, good real-time performance and strong scalability [5].

The equivalent device signal conditioning box completes the conditioning and expansion of the analog signal collected by the wired front-end equipment, and at the same time, the function of collecting the command signal issued by the wired front-end equipment can be realized through the relay conditioning circuit. The conditioning box no longer adopts the special design method for special machines. The signal conditioning module is designed with a general circuit module, and the conversion of various functions is realized through jumpers. The structure of the signal conditioning box adopts the pluggable design of the sub-mother board and the generalized design of the maximum envelope, which can meet the functional requirements of the signal conditioning box of multiple aircrafts at the same time.

According to the modeling and analysis of the voltage pulse commands sent by the wired front-end equipment, the types of voltage pulse commands can be divided into the following types:

a) Wired front-end command power supply on-off type command;
b) Equivalent command power supply on-off type command;
c) reset type instruction;

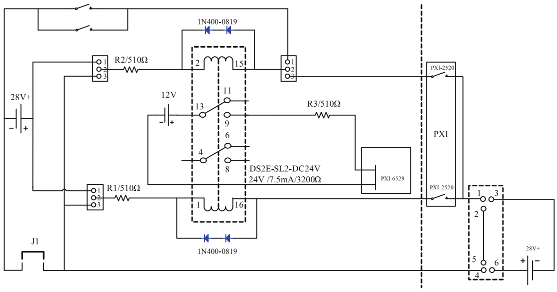

Fig. 4. Principle diagram of voltage pulse command signal acquisition

Based on the modeling and analysis of the contact type instructions sent by the wired front-end equipment, the contact types can be divided into the following types:

a) Wired front-end command power supply command;
b) Equivalent command power supply command;
c) The normally open contact closes a valid command;
d) The normally closed contact disconnects the valid command;

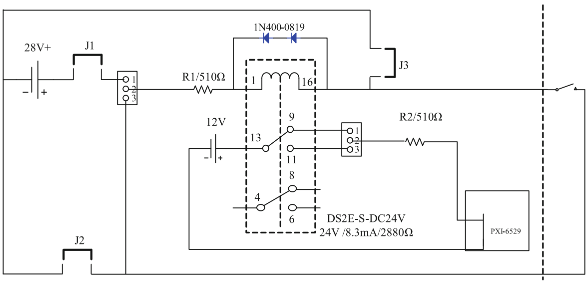

Fig. 5. Schematic diagram of contact type command signal acquisition

Based on the analysis of the signal model of the command, seven classic interface cables are summarized. Through the isolation, conditioning, gating and merging of the interface circuit, a general circuit can be used to adapt to a variety of command interfaces.

2.3 Software Design

The software of the equivalent simulation system has a clear function division in the top-level design, and the execution of the functional modules is independent of each other, so as to avoid the interference between each module in the program operation [6]. If a module needs to be revised, you can directly modify the corresponding module, which is convenient for maintenance. There is no need to modify the overall software architecture, which shortens the cycle of secondary development.

The network communication module mainly realizes the communication between the equivalent simulation system and the front-end devices, receives the command information sent by the front-end settings through the network, and feeds back the equivalent response results. The external structure of the network communication module is a While loop structure, and the internal structure is a conditional selection structure. According to the communication protocol, it initiates a connection to the designated port of the designated IP, receives the instruction information of the destination IP, and feeds back the execution information and various digital collection information.

This module simulates the response of the aircraft to hard-wire commands. The software module adopts a sequential loop structure design, controls the hardware module through function calls, reads the measurement results, and reads the collected hard-wire command voltage, pulse width, and command polarity. And the collected state is displayed visually, and the action state and signal waveform are displayed. The collection results are stored in the format of time, instruction name, and data result.

The pyrotechnic action test module realizes the acquisition, recording and display of the signal waveform of the pyrotechnic state quantity of the front-end equipment. Adopt While loop structure design, loop waiting and identify instruction information. In the front panel setting options, the pyrotechnic commands and corresponding polarities can be configured in tabular format, with command storage and query functions, including information such as name, time, signal waveform, polarity position, etc., which can be flexibly expanded with hardware sampling boards.

The load control module uses the script design method to design the load characteristics of the key working sections of the aircraft based on the equivalent model, including steady-state load, load step, load characteristics of the sunlit area and shadow area, form a response script, and test different load characteristics Under the power supply characteristics, and collect and record information including voltage fluctuation, current fluctuation, fluctuation rate and so on.

The automatic test module realizes the automatic test of wired command function, analog and digital quantity acquisition, load dynamic change, and pyrotechnic state quantity collection. The test is initiated by pressing the button, and the test is sent one by one according to the content of the configuration module. The software designs a data analysis module. The information collected and output by the simulator can be quantitatively analyzed, including state out-of-limit information, signal slope, frequency domain information, signal jitter, action time, etc., to facilitate rapid analysis of test data, and data analysis results can be displayed in the form of curves It is displayed, and the automatic generation of the report of the tested data is completed.

The main software interface functional area includes network connection area, instruction detection display, pyrotechnic simulation test area, load simulation test area, automatic script test area, data analysis and report function area. In the process of software writing, a generalized design is adopted, and the generalization of the software is realized by changing the configuration file. The configuration content of the parameter instruction includes the configuration of the network connection of the test model, the configuration of the PXI board, the configuration of the parameter channel, the configuration of the parameter The configuration of the instruction test content. It includes functions such as parameter calling, simulation control, parameter real-time monitoring, and simulation process input, and can configure simulation mode, simulation time, and initial state.

3 System Application and Verification

Based on the power supply and distribution equivalent system built by reconfigurable modules, the power supply interface and power supply and distribution equipment of multiple modules of the space station are simulated and verified. Firstly, according to the equivalent device model, the power supply interfaces and power supply and distribution parameters of the multiple cabins under test are structured and organized to form a configuration file, which is imported into the simulation system in batches, and the power supply and distribution equipment of each cabin is verified in turn. It has been verified that the system realizes rapid quantification of technical status on the basis of model analysis, and can seamlessly verify the interfaces and equipment of multiple cabins. Power characteristics and frequency domain characteristics are displayed in the form of visualization. A general, fast, comprehensive and deep equivalent simulation test is realized. After testing, verification and review, the system can effectively cover the interfaces of the tested object, cover normal and fault conditions, cover the power supply mode, and can quickly reconfigure.

4 Conclusion

This paper expounds the reconfiguration design method of the multi-spacecraft equivalent simulation system from the aspects of model, architecture, hardware and software. High. The simulation verification shows that the it has the ability to simulate real spacecraft, can be quickly configured, and simulate various interfaces between spacecraft, and can set failure modes. A unified interface is established, which reduces the difficulty of development and significantly reduces the cost. Solve the problem of waste of resources of the test system and high production and maintenance costs caused by complex test objects, many test equipment and low test resource utilization. It has important value for the development of space rendezvous and the technical verification of combined operation.

References

1. Chen, H., Ye, Y., Shen, S.: A measurement system equivalent device design Comput. Measurem. Control **20**(5), 1414–1919 (2012)
2. Liu, X., Wang, M., Jiang, H., et al.: The design and realization of an equivalent device of an intelligent pyrotechnic device based on FPGA. Electronic Measurem. Technol. **35**(5), 78–82 (2012)

3. Yu, J., Yan, S., Liu, X., Liu, W., Gao, J.: Design of modularization and generalization equivalent test system. Electr. Dev. (10), 1178–1184 (2012)
4. Zhang, H.: Hardware modularization and software configuration design ideas of spacecraft power supply and distribution test equipment. Spacecraft Eng. **01**, 72–76 (2010)
5. Men, B., Zhang, R., Zhou, N.: Universal design of spacecraft power supply and distribution test system. Aerospace Measurem. Technol. (12), 57–62(2018)
6. Su, H., Shen, S., Liu, W., et al.: Design of multifunctional equivalent device based on USB and FPGA. Television Technol. **36**(23), 50–54 (2012)
7. Li, L.: Interface design technology of satellite power supply and distribution test equipment. Spacecraft Eng. **01**, 66–72 (2002)
8. Zhang, L., Sun, N., Yu, H., et al.: The design and realization of satellite integrated test system based on PXI. Comput. Measurem. Control **16**(1), 27–29 (2008)
9. Zhang, F., Chen, L., Jing, X.: Design of automatic test equivalent device system for manned spacecraft based on PXI modular instrument. Comput. Measurem. Control **22**(6), 1671–4598 (2014)
10. Chen, X., Zhang, Y.: LabVIEW8.2 programming from entry to master, pp. 56–80. Tsinghua University Press, Beijing (2007)