Research on the Integration of Launch Vehicle Test and Fault Diagnosis

Jingwei An¹, Long Cheng²*, Weiqi Xie² and Yunlong Hu¹

¹Graduate School, Space Engineering University, Beijing, China
²Department of Aerospace Science and Technology, Space Engineering University, Beijing, China

*Corresponding author: cl_13@sohu.com

Abstract. According to the current situation of launch vehicle testing and fault diagnosis being carried out independently and with a high degree of manual participation, a plan of organically combining rocket testing and fault diagnosis for an integrated overall design is proposed, which is conducive to improving system integration and shortening the test cycle. Based on the analysis of the existing technology, the author respectively proposed a process-driven automatic test technology and a fault diagnosis method with an extended expert system as the core and a combination of multiple fault diagnosis technologies, aiming at the two core technologies in the integrated solution –automatic testing and fault diagnosis.

Keywords: Fault diagnosis, integration, process driven, expanded expert system.

1. Introduction

The carrier rocket system is complicated in composition. In order to ensure that the rocket successfully completes the established mission to the greatest extent, it is necessary to use ground equipment to conduct sufficient tests[1], and locate and solve the faults found in the test in time. At present, Chinese carrier rockets basically require manual on-site participation in testing, operation, and inspection[2]. In order to reduce the risk of misoperation that may be caused by manual participation, each test post is generally equipped with dual posts, which increases labor costs. Due to the lack of a fast auxiliary diagnosis system, technicians can only power up the suspected faulty parts based on their own experience and technical data such as circuit diagrams when faced with faults in the test, which not only wastes resources, but also speeds up the aging of the rocket equipment [3]. When the on-site commander is unable to troubleshoot the fault, he has to rely more on the experts of the rocket design and manufacturer to investigate the possible fault locations one by one.

In this traditional mode, rocket testing and fault diagnosis are two sequential and independent steps. Taking the test equipment of a certain type of launch vehicle control system in service in China as an example, after the technicians complete the test of the rocket according to the test procedures, the test data is transmitted to the back-end computer via the network switching equipment and saved in the form of files. During data judgment, the basis of judgment is read and compared with the test data. If the data is abnormal, it will be submitted to the fault diagnosis department for further fault confirmation and troubleshooting. This step-by-step, sequential method consumes a lot of time in the middle links. At the
same time, the efficiency of testing and fault diagnosis under manual participation is low, and the test cycle is long. With the rapid development of China aerospace industry, space launch missions are increasing rapidly. The testing and fault diagnosis methods under the current mode have been difficult to meet the requirements of high-density and high-reliability emission. Taking technical measures to improve the level of test automation and fault diagnosis intelligence, and organically combining rocket testing and fault diagnosis into a whole, reducing the time consumption of middle links is an important way to solve this problem.

2. Overall design plan of Integration

The integration of testing and fault diagnosis refers to the organic combination of launch vehicle testing and fault diagnosis under one framework, and it does not need to be completed in separate steps. Under this system, technicians will rarely intervene in rocket testing and fault diagnosis, and only need to troubleshoot the fault according to the fault location given on the user display interface.

The overall integrated design scheme is shown in Fig.1.

![Figure 1. Integrated overall design plan for testing and fault diagnosis](image)

The system is built on the basis of automatic testing and intelligent fault diagnosis. Based on the analysis of existing technologies, the author proposes a process-driven automatic testing technology and a fault diagnosis method with an extended expert system as the core and a combination of multiple fault diagnosis technologies. They will be discussed separately below.

The entire integrated system has three major functions—automatic launch vehicle test, automatic judgment of test data, and intelligent fault diagnosis. The process-driven automatic test technology can complete the rocket test without manual intervention. The test data is sent to the test data management
database and then automatically compared with the standard value parameters. The comparison results and the original test data are displayed in the user interface, and the original test data is stored in the database of previous data for later review. After data preprocessing, the original data is sent to a fault diagnosis system with an extended expert system as the core and a combination of multiple fault diagnosis technologies. Finally, the diagnosis results are displayed on the user interface. The design integrates testing, data judgment, and fault diagnosis in the same system. This integrated design simplifies the launch vehicle ground test equipment, eliminates the middle link between testing and fault diagnosis, and shortens the test cycle. Intelligent fault diagnosis can eliminate most of the faults found in the test and improve the efficiency of rocket ground testing.

2.1. Process-driven Automatic Testing Technology

In traditional rocket testing, automatic testing is mainly completed in accordance with the given test process and steps, from top to next step. All test parameters, control instructions, and test results are built into the test software [4]. When one of them changes, you need to recompile. The test software development takes a long time, takes up a lot of memory, and is not generic enough. At the same time, frequent instruction scheduling reduces the availability of CPU.

Based on the above problems, a new automatic testing method is proposed—a process-driven automatic testing method. The system is divided into three parts: test process database, test data management database and database of previous data. The composition of the process database is shown in Fig.2.

![Figure 2. The composition of the process database](image)

The user interaction module is responsible for the human-computer interaction during manual testing, and it is used to read the operating instructions entered by the technicians. The test process module breaks down the rocket test process according to levels, and stores the test process of each test item. The component under test information stores the basic parameter setting of the tested component, such as the test channel number, etc. Instrument description and drive module drives the instrument to test according to test instructions. The test task matching and scheduling module is the core of the process database. It is responsible for matching the manually input test instructions to the test process database, determining the starting point of the test, scheduling and controlling the instrument for testing according to the test sequence given by the test process module, and sending the test data enter the test data management database. The test data management database stores the standard value parameters, receives the original test data sent by the process database and compares it with the standard value. It sends the original data to the database of previous data for storage, and displays the data and results on the user interface. The database of previous data stores the original data obtained from previous tests for analysis afterwards. During standard value parameters collection, standard value parameters under different conditions should be collected through various means. After establishing a complete standard value
parameter, its attribute should be set to read-only to prevent abnormal data. The system structure of the entire automatic test is shown in Fig.3.

When performing automatic tests, the test task matching module will match the test tasks to the head of the test process module, and then the test scheduling module will automatically read the records from the test process module one by one in order, and follow the "read one line, execute one line, and execution complete, then continue to read, continue to execute until the last record" principle, all test items can be completed without manual participation in testing, data display, storage and other tasks. The execution process is shown in Fig.4.

It can be seen from the flow chart that the completion of all test items is driven by the test process module. This structure can greatly improve the repeatability and reliability of the test software. When the test item changes, only some test modules need to be modified, and only the corresponding standard value parameters need to be added to the test data management database. The database of previous data is separate from the other two databases and has strong versatility. It can be split and used as database of previous data for other types of rockets.

![Figure 3. Automatic test structure diagram of process-driven database](image)

2.2. Research and Analysis of Intelligent Fault Diagnosis Methods

With the application of new technologies in launch vehicle and the increase in rocket launch density, the original manual-based fault diagnosis methods have become increasingly difficult to apply. With the development of computer technology and artificial intelligence, rapid and intelligent rocket fault diagnosis has become possible. According to the literature [5, 6], the current commonly used and widely studied fault diagnosis techniques mainly include

1) Threshold value judgment. It is the earliest and most commonly used processing method. When the measured signal exceeds the threshold, an error is reported. This method avoids the dependence on the mathematical model, but it has a large amount of calculation and can only be used for static or slowly changing signals.

2) Model-based fault diagnosis method. Using numerical simulation methods to find faults through the establishment of mathematical simulation models or design models. It can be seen as a "predictive model". However, the model is relatively large and the diagnosis speed is slow, and the diagnosis result depends on the accuracy of the model due to the use of the system model.
(3) Reasoning mechanism based on self-learning. This method mainly uses anomalous algorithms to discover anomalies by analyzing the data set. Its representative technology is fault diagnosis technology based on neural network. Neural network can be used to deal with complex nonlinear systems. Due to the parallel method, the diagnosis speed is very fast; it has strong fault tolerance and self-adaptability. However, this method cannot reveal some potential relationships within the system and cannot give a clear explanation for the diagnosis process [3].

(4) Fault diagnosis technology based on fuzzy logic. Fuzzy fault diagnosis is a method of establishing a fuzzy relationship equation between faults and symptoms. It can reflect the fuzzy relationship between the fault symptoms and the cause, and the diagnosis is convenient. However, the determination of the membership function that affects the validity of the result in the fuzzy diagnosis needs to be further studied.

(5) Fault diagnosis method based on Petri net. This method can dynamically describe the process of fault generation and propagation, but the process of establishing and perfecting the Petri net is complicated. When faced with the same fault characteristics, it is very difficult to locate the fault source.

(6) Fault diagnosis method based on information fusion. This method uses various sensors to add to the key equipment of rocket to comprehensively process the operating status information of the equipment, and finally comprehensively obtain the system fault. However, this method requires additional sensors, which increases the cost and reduces the reliability of the rocket.

In summary, different fault diagnosis technologies have their own advantages and disadvantages. For launch vehicles with complex systems, it is necessary to integrate multiple intelligent fault diagnosis technologies.

Figure 4. Automatic test flow chart
2.3. Expanded Expert System.

The expert system means that the computer comprehensively uses the content of the expert knowledge database according to the collected data, calls various applications when necessary, and asks the user for necessary information during the operation process to quickly find the final fault or most likely faults [6]. The expert system usually consists of six parts: a comprehensive database, an expert knowledge database, an inference module, an annotation module, a knowledge acquisition program and a human-machine interface. This traditional expert system has a strong dependence on past experience. It is more effective in diagnosing repetitive faults, but it can almost do nothing about new faults that have never occurred before. Based on the traditional expert system, the author adds predictive modules and comprehensive decision-making modules to form an extended expert system. The system block diagram is shown in Fig.5.

When the system works, the test data is sent to the database, then the data is preprocessed to make it meet the format requirements of the fault extraction module, prediction module and inference module. After the data is preprocessed, the fault extraction module uses standard value parameter comparison method, threshold value judgment method and other methods to extract abnormal data. The system uses methods such as rule-based reasoning, fault tree diagnosis technology and case-based reasoning in the inference module to match with the expert knowledge database which stores professional knowledge. If the fault can be determined in the expert knowledge database, the system will display and output where the fault is located.

![Figure 5. Block diagram of the extended expert system](image)

If the corresponding fault mode cannot be matched in the expert knowledge database, the inference module will use self-learning inference, fuzzy logic inference and other methods to infer fault, and the prediction module will use model-based fault diagnosis methods and fault estimation algorithms to predict fault. When there is a difference between the faults obtained by the inference module and the prediction module, the faults will be submitted to comprehensive decision-making module for arbitration. The comprehensive decision-making module comprehensively obtains the fault location based on the voting mechanism and other methods. If the comprehensive decision-making module cannot get the fault, user display interface will display the predicted fault and inferred fault together, and request manual assistance.

3. Conclusion

Process-driven automatic testing and a fault diagnosis method with an extended expert system as the core and a combination of multiple fault diagnosis technologies are organically combined and carry out integrated overall design in order to solve the problems that the testing and fault diagnosis of active-
duty carrier rockets are carried out independently in order, the degree of manual participation is high and it is difficult to be qualified for Chinese high-density space launch mission in the future. The design has the functions of automatic testing, automatic data judgment, and intelligent fault diagnosis. The middle links of testing and fault diagnosis are omitted, manual operations are reduced, the integration level of the entire ground equipment is improved, and the test cycle is shortened. It is hoped that the integrated design of testing and fault diagnosis in this article can contribute to the realization of high-density and high-reliability space launches in the future.

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