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Research Status and Prospect of Equipment Testability Experiment and Evaluation Technology

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Abstract

Testability experiment and evaluation are the key technologies of equipment testability engineering. It is also an important factor that restricts the development and application of testability technology. In recent years, testability experiment and evaluation are the focus of research in the field of testability. The research status and characteristics of testability prediction, testability virtual experiment, testability semi-physical simulation experiment, fault injection and testability evaluation technology are reviewed, and the development trend of testability experiment and evaluation technology is discussed, which can provide references for testability research of domestic equipment.

Keywords

Testability;virtual experiment;semi-physical simulation;fault injection;comprehensive evaluation.

1. Introduction

The "Regulations on the Management of General Quality Characteristics of Equipment" clarifies the "six characteristics" requirements for the full life cycleof equipment, namelyreliability, maintainability, supportability, testability, safety and environmental adaptability. Testability, as one of the "six characteristics" of equipment, refers to a design feature that the equipment can accurately determine its status (working, inoperable, or performance degradation) in time and effectively isolate its internal faults [1]. Good testability design can improve equipment's fault detection and fault isolation capabilities, improve equipment maintenance support level and combat readiness, and reduce equipment life cycle costs [2-3].

Theconcept oftestability wasfirst proposed by F. Liour and others in the article "Equipment Automatic Testability Design" in 1975, and was later applied to the fieldof circuit diagnostics design, withhecontinuousimprovement of equipment performance and the rapiddevelopment of information technology. ,Testability has gradually received more attention. In 1985,the "Electronic System andEquipment TestabilityProgram"MIL-STD-2165 issued by the U.S. Department of Defense took testability as adesign requirement equivalent to reliability and maintainability, marking that testability has become a subject to reliability and maintainability. The parallel independent disciplines have further developed the testing technology [4]. Relevant information shows that the US military has relied on more than 30 years of testability theory and technology accumulation, and has widely applied testability design to advanced weapons and equipment such as aircraft and missiles, and achieved good results. For example, the F-22 "Raptor" has been tested and designed, and within a 20-year life cycle, the cost of use

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and support is 30% lower than that of the F-15 [5]. Since the mid to late 1980s, my country began testing research and has made great progress. "Equipment Testability Program" GJB2547-1995, "Equipment Testability and Diagnostic Terminology" GJB3385-1998, "Failure Mode, Impact and Criticality Analysis Guide" GJB/Z1391-2006 and "General Requirements for Equipment Testability Work" have been promulgated successively GJB2547A—2012 and other relevant standards in the field of equipment testability. Testability technology has been widely used in spacecraft, aircraft, missiles, radars and other equipment [6-9].

With the continuous advancement of equipment testability design technology,how to evaluate whether the equipment testability index meets the specified requirements has become a key issue facing the testability work. The testability design of the equipment is not accomplished overnight. It requires continuous experimentation and improvement iterations to achieve an increase in the testability level. Therefore, effective testability test methods and scientific testability evaluation methods are essential to improve the testability level. Testability test refers to the verification test carried out to determine whether the equipment meets the testability requirements; testability evaluation refers to the quantitative evaluation of the equipment's fault detection rate, fault isolation rate and other indicators. The result of the testability test is the data source of the testability evaluation, and the testability evaluation is the ultimate goal of the testability experiment. The two are inseparable and form a whole.

The US military standard"Maintenance Verification, Verification and Evaluation" MIL-STD-471A first stipulated the equipment testability test and evaluation rules in the formof military standards,andthe British military standard Def Stan 00-13/Issue 3alsoincluded thetest test content. And methods have been stipulated,and after years of experience and technology accumulation, countries such as the United States and Britain have established scientific and complete testing and evaluation systems [10]. my country has clarified the purpose and requirements of testability test and evaluation in the "General Requirements for Equipment Testability Work" GJB2547A—2012. It is currently a guiding document for conducting testability tests and evaluations in China, but the content is not detailed enough and the operability is not good enough. The domestic research in this area is not perfect, and systematic testing and evaluation work is generally not carried out before the equipment is delivered, which restricts the development of equipment test engineering. Therefore, carrying out research on testability tests and evaluation technologies and realizing the closed loop of equipment testability engineering are of great significance to the development of equipment testability in my country.

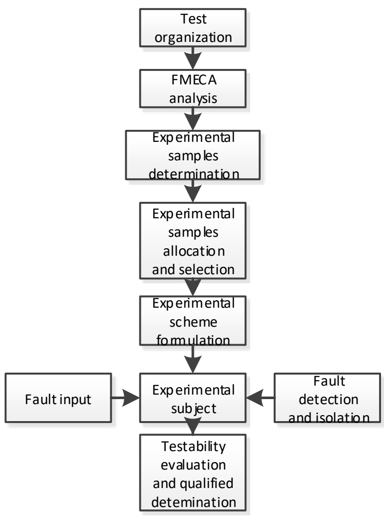

Figure 1 Flow chart of testability test and evaluation

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2. Testability test and evaluation process

The testability test and evaluation process is shown in Figure 1. It mainly includes the establishment of test organization, product technical status confirmation, product failure mode analysis, testability test plan design, testability test implementation and testability index evaluation, among which test plan design, test implementation and index evaluation are the key.

3. Analysisof the status quo of testability test technology

3.1. Non-physical test technology

3.1.1. Testability prediction technology

Testability prediction refers to estimating whether the current testability index ofequipment meets the specified requirements through engineering analysis and calculationaccording to testability design data, and then evaluating the testability work that has been carried out, checking missions and filling deficiencies, and immproving the design. The testability prediction method is mainly through the establishment of a qualitative model, as shown in Figure 2. In the last century, foreign countries have carried out a lot of research on testability qualitative models, proposed logic models, information flow models, multisignal models and hybrid diagnosis models, and developed modeling software such as teams and Xpress, which are applied to testability simulation evaluation of missile, aircraft and other equipment. At the beginning of this century, China began to study testability modeling. In view of the shortcomings of the above models, such as large error and limited application range, some new modeling methods are proposed. Based on the systematic analysis of the characteristics of the above models, Zhang Yong et al. [11] proposed an integrated function fault behavior test environment model that can quantitatively describe the testability information of equipment; Dai Jing et al. [12] proposed a new system testability modeling method based on object-oriented Bayesian network and state test correlation sensitivity index, and considered the uncertainty in the test of complex electromechanical system, and carried out testability modeling analysis of aircraft fuel system; Zhai Yuyao et al. [13] proposed a testability modeling method based on Generalized Stochastic Petri net, established the testability model of missile, solved it by isomorphism method, and obtained the testability index of missile subsystem. Domestic research institutions have also successively developed testability modeling software, such as TADS developed by National University of Defense Science and technology, TEID developed by Beijing University of Aeronautics and Astronautics, testability Da developed by University of Electronic Science and technology, which has played an important role in equipment testability design and evaluation.

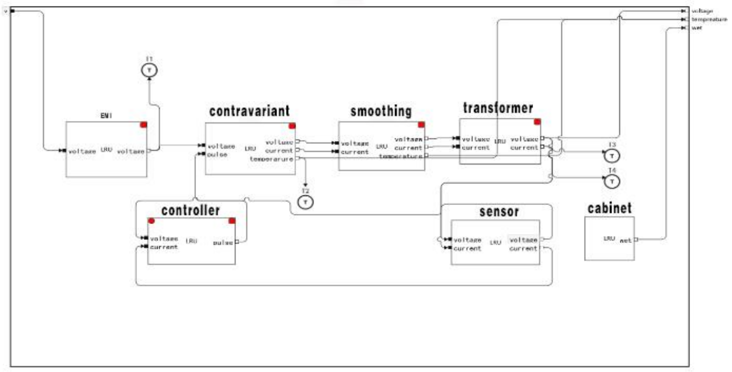

Figure 2 Testability multi-signal model of a certain type of inverter

Through modeling software, thetestability model is established from the perspective of equipment information flow. The modeling process is simple, which is convenient for engineering realization, and the testability index of equipment can be predicted quickly.

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However, because most models do not consider the uncertainty of testing, the randomness of failures, environmental factors, etc., the results of testability predictions often deviate greatly from the actual ones. The quantitative testability model considers the above influencing factors, and the established model is more accurate, but the modeling process is complicated and requires more information, which is not applicable to new research equipment. Therefore, the testability prediction result is usually used as a reference for testability improvement design and a priori distribution data for testability evaluation.

3.1.2. Testability virtual test technology

Testability virtual test is to carry out fault injection and fault detection isolation tests on equipment virtual prototypes, statistical test results, and calculate testability indicators. Its essence is the application of modeling and simulation technology in the field of testability tests. The basic process is shown in Figure 3. Show.

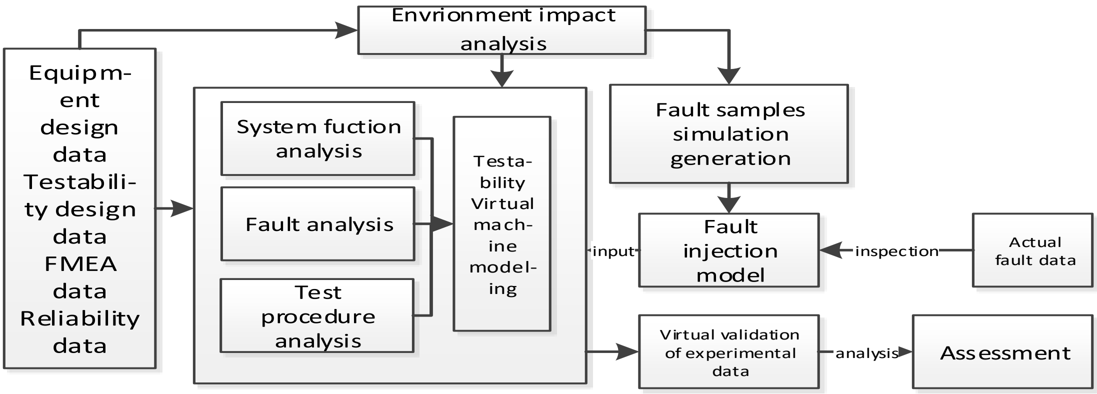

Figure 3 Basic process of testability virtual test

The testability virtual test does not require special hardware support, can be carried out inthe early stageof development, can accurately inject multiple failuremodes, richtest data,and low cost. Foreign countries have long applied simulation technology to the testability test of equipment. In 1997, the US Department of Defense issued the "Simulation, Test and Evaluation Process Guidance Manual" to guide the application of simulation technology in testability test [14]. Due to the use of test-based virtual tests for the US "Sidewinder" and "Patriot" missiles, the research cost is reduced by 10%-40% and the development cycle is shortened by 30%-40% [5].

Due to the relatively weak simulation modelingtechnology, there is a big gap between domestic testability virtual test technology and foreign countries. At present, testability virtual test is mainly used in electromechanical products. Zhao Chenxu[15] used Multisim to establish a virtual prototype of a heading and attitude system, carried out fault injectionand detection experiments, and calculated the testability index of the system based on the test data analysis; Liu Ying [16] based on Modelica language and Dymola simulation platform, established A testable virtual prototype of a heading and attitude system was carried out, and a testable verification test was carried out; Zhao Wei [17] established a model of a high-voltage power supply for aerospace based on Saber, and conducted a virtual fault injection test; Wang Libing et al. [18] used PSpice to test a certain electronic equipment drive protection circuit has been tested virtual test. In summary, the testability virtual test technology has great advantages in testability verification. In theory, any failure mode can be injected at any position and at any time of the virtual prototype, and it can be repeatedly tested to collect sufficient information. Test data, but the main problem is that the accuracy of the virtual prototype cannot be guaranteed, and there is often a big gap between the actual verification.

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3.2. Hardware-in-the-loop simulation test technology

Semi-physical simulation refers to Hardware in the Loop Simulation, which refers to the real-time simulation of connecting some physical objects in the simulation system [19]. In the semi-physical simulation test, the equipment unit that is not suitable for the physical object can be run in the computer with a mathematical model, and the other parts are used in the physical object to construct a closed-loop control semi-physical real-time simulation environment. The basic principle is shown in Figure 4.

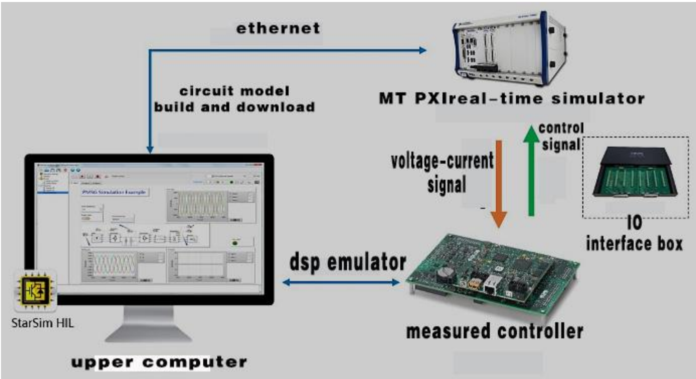

Figure 4 Schematic diagram of semi-physical simulation

The semi-physical simulation technology has been widely concerned and researched sinceits inception in the 1960s. The United States has established anumber of semi-physical simulation laboratories. The semi-physical simulation technology has been applied in many fields such as aviation, electrical engineering, and chemical engineering, especially it is the field of weapon equipment research and development. The use of semi-physical simulation technology can greatly shorten the development cycle. According to statistics, the United States has adopted semi-physical simulation technology in the development of missiles such as Roland, which reduces the number of experiments in the live ammunition range by more than 30% [20]. At present, foreign hardware-in-the-loop simulation technology is relatively mature, and hardware-in-the-loop simulation platforms such as dSPACE, RT-LAB, xPC and NI are widely used. The domestic semi-physical simulation technology has reached a high level in many fields. The Galaxy high-performance simulation platform of the National University of Defense Technology has played an important role in the development of the Long March series of rockets and multi-model missiles.

Semi-physical simulation test technology also has related applications in equipment testability verification. Wu Zhe etal. [21] carried out digital simulation of the aircraft fuel system that is not suitable for the airborne fuel measurement system. The measurement part adopts the physical object and uses a variety of faults. The injection method realizes the typical fault simulation of the system under test and verifies the testability index of the system under test; Li Zhiyu et al. [22] designed a fault injection software and hardware system based on hardware-in-the-loop simulation, and applied it to the testability of radar equipment During the verification, the reliability of the semi-physical simulation test was verified by comparison with the actual measurement results. It can be seen that the hardware-in-the-loop simulation test technology can be better applied to the testability verification test of equipment. Compared with the virtual test, because the hardware-in-the-loop simulation test is connected to some physical objects, the reality of the simulation can be better realized. Confidence is higher.

3.3. Physical test technology

Testability physical test refers to injecting faults into equipment through a fault injection device under laboratory or actual use environmental conditions, and using prescribed methods to detect and isolate the equipment, and to judge the testability level of the equipment through the test results. Therefore, fault injection technologyis the key to carrying out test-based physical experiments. Fault injection methods generally include software fault injection and hardware fault injection. The hardware injection methods mainly include fault injection through the external interface of the equipment,fault injection through probes, fault injection through a dedicated adapter board, and pluggable fault injection, etc. ; Software fault injection is mainly through changing the source code inside the equipment, and activate the fault when the equipment is running. Shi Xianjun, Hu Yu, Li Jialiang, etc. [23-25] summarized the method of equipment fault injection, and analyzed the applicable occasions, advantages and disadvantages of the fault injection method. In general, the use of fault injection to carry out test-based physical tests can simulate the real fault conditions of equipment, and the reliability of the test results is higher than that of virtual and semi-physical tests. However, fault injection is easy to cause damage to the equipment, and the test cost is high and the risk is high. For tightly packaged equipment, it is difficult to inject some faults, which leads to unreasonable fault sample structure and unreliable test results. In response to these problems, the researchers established an equivalent fault injection method. Yan Shigang [26] used the fault transfer characteristics to establish the relationship between faults and states, and used Bayesian networks to obtain equivalent faults, which solved the problem of naval munitions packaging. The problem of difficult fault injection caused by rigorous; Qiu Wenhao et al. [27] established the equivalent fault injection method of the "failure mode-function-state" fault behavior model, which increased the fault injection rate of a certain equipment launch control system by 16.7%; Chen Ran [28] analyzed the relationship between the equipment chromatogram and the level based on the hierarchical model, and realized the expansion of the fault injection sample size according to the principle of behavior equivalence; Li Tianmei et al. [29] established an airborne stability tracking platform based on the fault transfer characteristics The fault injection method effectively solves the injection problem of inaccessible faults at 7 locations.

Testability physical test technology can reflect the testability level of equipment to the greatest extent, and it is still an important means of equipment testability test at present.

4. Analysis of the status quo of testability evaluation technology

Testability evaluation refers to the quantitative evaluation of equipment testability indicators such as fault detection rate, fault isolation rate, false alarm rate, etc., to determine whether the equipment is accepted/rejected. Testability evaluation is a key step of the entire testability project. Only by scientifically conducting testability evaluation of equipment and obtaining the real testability indicators of the equipment can we better improve the testability of the equipment and realize the growth of the level of equipment testability. At present, there are two main methods of testability evaluation: one is to use test to test data based on classical statistical theories such as point estimation, interval estimation, approximate estimation, etc.; the other is to integrate multi-source data in test engineering practice. Such as expert information, testability test data, use stage data, etc. small sample theory. Based on the evaluation method of classical statistical theory, when the amount of testable test data is sufficient, more accurate testability indicators can be obtained. However, because engineering applications are often limited by test cycle and cost, it is difficult to carry out a large number of testable tests, especially field tests, which require a lot of manpower, material and financial resources, and the sample data obtained is less, and the sample structure is unreasonable , Resulting in the evaluation result not being recognized.

In response to this problem,comprehensive testability evaluation methods using information from each stage of equipment development have received widespread attention.Li Tianmei et al. [30] established a comprehensive evaluation model based on the Bayesian statistical theory, using expert experience, testability and other data as prior information,and effectively fusing it

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with field use data, which effectively improved the confidence of the evaluation results; Zhang Xishan et al. [31] Aiming at the subjectivity and singularity defects of prior information fusion, the uncertainty measurement and support index were proposed to improve the confidence of the evaluation results; Xu Baorong [32] passed the test data and the field use data. Reliability is weighted, and a comprehensive evaluation method based on the credibility of test results is constructed; Wang Jing et al. [33] proposed an equivalent conversion method for several common test information, which realized the success or failure of various types of data. , And proved the effectiveness of the proposed method through a case. The small sample theory based on multi-source data processes data in different forms to obtain a mixed prior distribution of multi-source data. On this basis, data from physical objects are merged to obtain testable indicators with higher reliability. The process is shown in Figure 5.

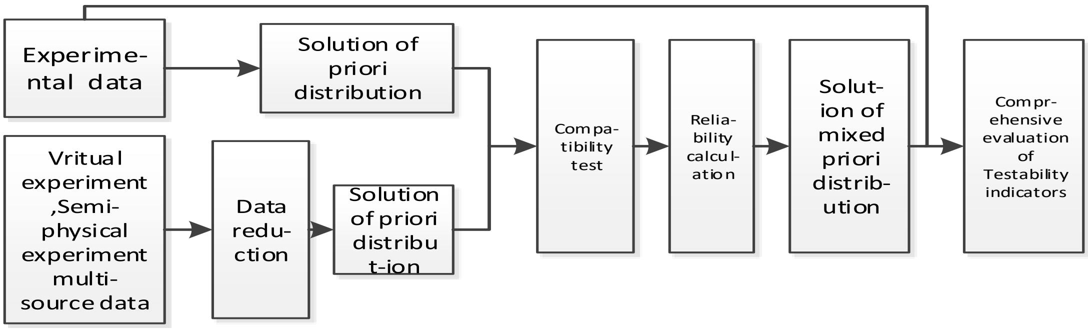

Figure 5 Testability comprehensive index evaluation process based on multi-source data fusion

5. Prospect of testability test and Evaluation Technology

5.1. Prospects of Testability Test Technology

(1) Testability prediction technology is relatively mature, and it can play an important role in analyzing equipment failure behavior and sorting out the optimal diagnosis plan. How to establish a quantitative and accurate model to make the testability prediction result more accurate is a key issue that needs to be solved in the future problem.

(2)The current domestic testing virtual and semi-physical simulation tests can be better applied to electromechanical equipment, but they cannot be implemented in all equipment and are not universal. With the continuous improvement of computer simulation modeling technology, virtual prototypes are established with the help of computers, and test virtual or semi-physical simulation experiments are carried out based on this, so as to realize the integration of testability requirement analysis, index allocation, in-machine test design, and test evaluation. Will become the direction of development in the field of test engineering.

(3)The development of testability physical test technology mainly depends on fault injection technology. How to reduce the damage caused by fault injection to equipment, enhance the accessibility of fault injection location, and perform multiple fault injection simultaneously requires further research.

5.2. Prospects of Testability Evaluation Technology

Testability comprehensive evaluation technology based on multi-source data fusion is the main research direction of current testability evaluation. The difficulty lies in how to establish an effective comprehensive evaluation model, process different types of testability data more scientifically, and improve the credibility of the evaluation results.

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With the continuous improvement of my country's economic strength and the increasing emphasis of equipment departments on testability, it will be possible to carry out physical field tests of equipment throughout the life cycle.

6. Conclusion

Althoughthe research of testability technology in my country started late, it has developed rapidly. It has achieved gratifying research results in testability testing and evaluation technology, testability modeling technology, testability requirement analysis technology, testability design technology, etc. Sexual engineering has realized the transition from the experience-based stage to the model-based design stage, and basically formed a complete set of testability technology system.

Testability testing and evaluation technology is the key to equipment testability engineering, and it is the key to determine whether the testability work can achieve a closed loop. For a long time, it is precisely because of the lagging development of testability test and evaluation technology that the testability index requirements are often empty during equipment acceptance, and it is impossible to scientifically evaluate whether the equipment meets the index requirements, making the testability work streamlined. With the continuous improvement of equipment complexity and intelligence level, the role of testability will become greater and greater. Testability test and evaluation technology must be continuously optimized in conjunction with equipment characteristics to meet the requirements of equipment acceptance and facilitate the development of equipment.

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