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Research on the Automated Testing Technology of Electrical Performance for Pyrotechnic Devices

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Abstract

This study investigates the automation upgrade of electrical performance testing for aerospace pyrotechnic devices, aiming to achieve automated testing and full-process digitalization. Through standardization of the testing, research on specialized adapters, automatic insertion technology for pins and holes, high-speed switching technique and data collection during the testing process, fully digital and automated electrical performance testing is implemented throughout the entire process. Field production verification indicates that the automated testing scheme achieves fully unmanned operation, reducing operator demand from 2 to 1. Overall production efficiency is improved by up to 6 times compared to manual testing. Compared with the over original forty types of electrical connectors, the system now uses only 5 specifications of specialized adapters to support automatic testing of over 100 pyrotechnic devices, reducing the number of specifications by more than 85%.

Keywords

Pyrotechnic Devices, Electrical Performance, Automated Testing

1. Introduction

Pyrotechnic devices [1] are extensively adopted in aerospace engineering. They serve as critical components to guarantee reliable implementation of aerospace missions. Strict fine-grained control is required for their manufacturing processes. Full lifecycle quality traceability shall be realized throughout production. Manufacturing of aerospace pyrotechnic devices involves various electrical performance tests, such as internal resistance measurement [2]-[4]. These electrical tests cover multiple production stages. They directly reflect the quality performance of pyrotechnic devices [5] [6].

Currently, electrical performance verification of pyrotechnic devices remains predominantly manual. Test results are read and evaluated manually. Conventional manual testing approaches can hardly meet the growing production demands and emerging industrial requirements. Manual data recording fails to realize efficient data synchronization. Obviously, this manual scheme has technical flaws, as follows:

1) High proportion of repetitive operations. Operators perform prolonged sedentary work, which may induce occupational health risks.

2) Low digitalization level of test instruments. Isolated data islands are formed, which impede unified product data management and restrict manufacturing digital transformation.

3) Low efficiency of manual testing. For multi-variety and small-batch production of pyrotechnic devices, numerous dedicated test adapters are required, resulting in complicated on-site management.

4) Dispersed layout of test stations. Test instruments occupy large floor space, accompanied by low overall equipment utilization.

Based on the above analysis, this paper investigates technological innovations for automated electrical performance testing of pyrotechnic devices. By developing key technologies such as specialized adapters for automated testing, automatic loading and unloading technology, and automatic mating technology, an automated electrical performance testing system was developed and successfully applied. Ultimately, the proposed scheme enables unmanned testing of pyrotechnic devices, thereby improving test efficiency and reducing labor consumption.

2. Pyrotechnic Devices Structure

A typical aerospace pyrotechnic device is selected as the research object. It mainly consists of a housing and electrode pins. Its structural characteristics are consistent with those of conventional pyrotechnic devices. The structure is shown in **Figure 1**. The main test positions for the electrical performance of the pyrotechnic device are the housing and the metal electrode pins. The device usually is equipped with two or four metal electrode pins, and the primary testing parameter is the internal resistance of the pyrotechnic devices.

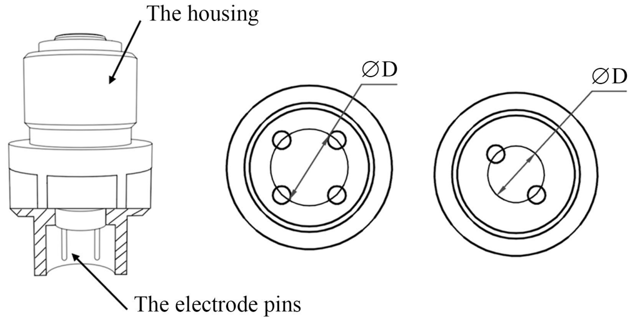

Figure 1. Schematic diagram of pyrotechnic device structure and electrode distribution.

3. Methods

3.1. Standardization of the Testing

After detailed investigation, more than 100 types of pyrotechnic devices require electrical performance testing, and their dimensions and test specifications differ significantly. According to the typical structure of pyrotechnic devices, the housing and metal electrode pins are defined as test points. As shown in **Figure 1**, the pyrotechnic device is configured with 2 or 4 metal electrode pins and one housing. Consequently, each device possesses a maximum of five test terminals. Terminals 1-4 are defined as electrode pin testing positions, and terminal 5 serves as the housing testing position. For two-electrode devices, only terminals 1, 3 and 5 are utilized, whereas terminals 2 and 4 are excluded from testing. The correspondence between test terminals and device structures is listed in **Table 1**.

On the automated testing system, electrical performance verification is achieved by measuring conductance between any two of the five points. This approach unifies test requirements and standardizes the test procedure for pyrotechnic devices.

Table 1. Correspondence relationship between test terminals and device.

test terminal number	device structure (4 pins)	device structure (2 pins)
1	Pin 1	Pin 1
2	Pin 2	/
3	Pin 3	Pin 2
4	Pin 4	/
5	housing	housing

3.2. Research on Specialized Test Module

More than 100 types of pyrotechnic devices are matched with over 40 kinds of electrical connectors [7]. These connectors are not suitable for the automated electrical performance testing. In accordance with standardization of the testing and connector structures, specialized test module is designed and investigated.

In this test module, probes [8] connect the electrode pins to test instruments, and copper blocks establish electrical contact with device housings. The connection configuration is illustrated in **Figure 2**. A dedicated adapter is designed to ensure steady contact between electrode pins and probes. Its three-dimensional model is shown in **Figure 3**. During testing, the device is mounted on the adapter. Bottom probes contact the electrode pins while copper blocks fit against the housing, enabling reliable electrical connection of all five test points.

In the test module, the probe is installed on the motor. Therefore, the distance between the probes can be freely controlled by the motor. However, the size on the adapter is fixed. In order to enhance the compatibility of the adapter during the automated testing process, the adapter was studied. According to the dimensional specifications of pyrotechnic devices, five types of specialized adapters are developed, mainly with primary differences in the spacing of the sockets. Compared with the over original forty types of electrical connectors, there are only five specifications of specialized adapters, reducing the number of specifications by more than 85%. The dedicated test modules are an important prerequisite for the automation of electrical performance testing, which effectively reduce testing costs and significantly facilitate the management and control of test fixtures.

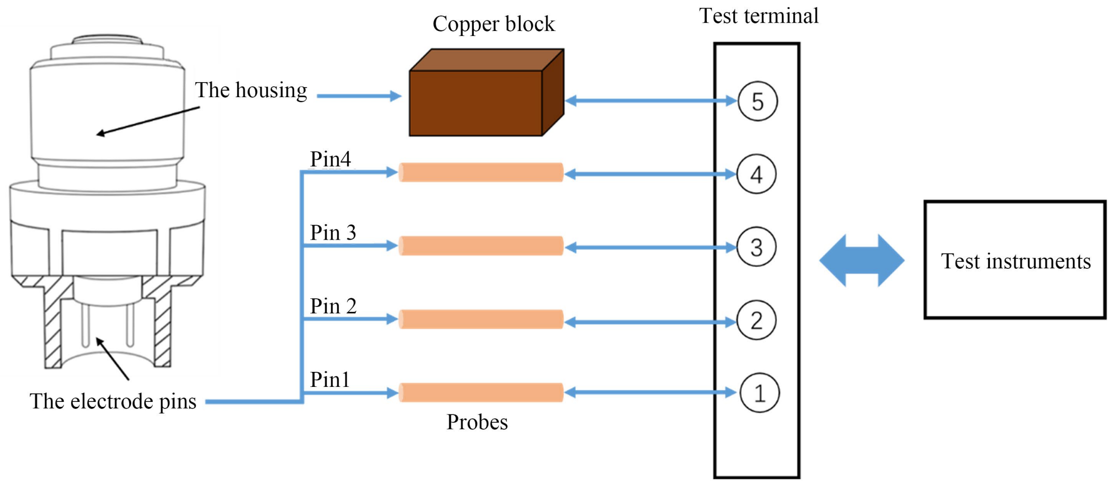

Figure 2. The diagram of electrical connection.

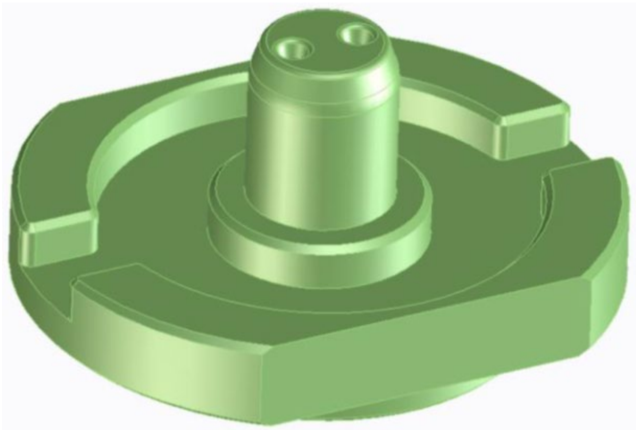

Figure 3. Three-dimensional model of the specialized adapters.

3.3. Automatic Insertion Technology for Pins and Holes

At present, electrical performance tests are manually performed by connecting pyrotechnic devices and electrical connectors. In the automated testing process, pyrotechnic devices must be automatically mated with test modules. Using specialized adapters, high-precision positioning of the four-axis robot, and the precise pin detection and guidance via vision cameras, the pins in the pyrotechnic devices are accurately inserted into the specialized adapters with guiding holes. This enables automatic mating between pyrotechnic devices with various specifications and specialized adapters. This solution achieves the positioning of pyrotechnic devices through simple hole-axis connection, and realizes electrical connection via variable probes. It addresses the pain point of frequent electrical connector replacement in conventional designs while significantly reducing connector consumption.

3.4. High-Speed Switching Technique

During automatic electrical performance testing, the pin spacing of initiating devices must be matched with specialized adapters of various specifications. To satisfy the requirements, a turntable-based testing structure was designed, as shown in Figure 4. Specialized adapters of various specifications are circumferentially arranged along the turntable edge. By rotating the turntable, the specifications of the specialized adapters can be switched quickly and precisely, without manual adapter replacement. This design improves the response speed of the switch of the specialized adapters, simplifies the testing process, and removes the need for manual replacement of the specialized adapter.

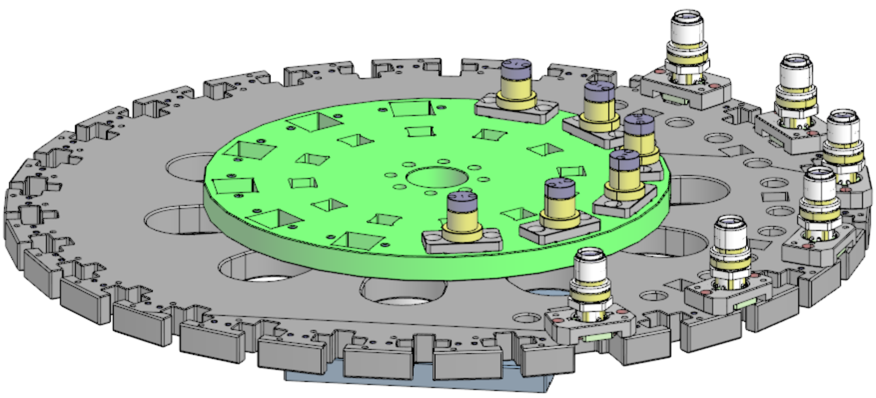

Figure 4. Schematic diagram of the electrical performance test structure.

This study investigates all the testing steps in the production process of pyrotechnic devices, and it is determined that low-resistance testing and insulation-resistance testing must be performed sequentially. Specifically, after loading and clamping the pyrotechnic devices, the two tests must be completed before unloading. In response to this process requirement, the automatic electrical performance testing system integrates the low resistance meters and the insulation-resistance meters. A matrix switch is employed to enable rapid switching between test instruments, thereby achieving sequential measurement of low resistance and insulation resistance. This solution simplifies the electrical performance testing process of pyrotechnic devices and effectively improves the efficiency of electrical performance testing.

3.5. Data Collection during the Testing Process

To realize digital acquisition and supervision of the production process, automatic collection and archiving of test parameters and results for explosive devices during electrical performance testing are implemented. Then the measured resistance is compared with the preset range. Any out-of-range reading indicates unqualified resistance performance. Therefore, without the need for manual intervention, the real-time judgment of equipment test results is achieved. This approach not only improves testing efficiency but also facilitates centralized data management for pyrotechnic devices.

3.6. The Overall Structure of the System

The overall system architecture is partitioned and designed functionally, including a four-axis robot, material tray, vision module, and test zone, as shown in **Figure 5**. Among them, the four-axis robot is used for grasping and moving the products. The vision module identifies pin sequences and enables precise rotational alignment and insertion. The test zone performs electrical performance verification of pyrotechnic devices. Additionally, the test zone consists of 6 test modules, allowing for the simultaneous testing of the resistance values of 6 products on the equipment. Insulation resistance meters, low-resistance meters, and other instruments are mounted at the base of the machine, realizing highly compact integration of the entire equipment.

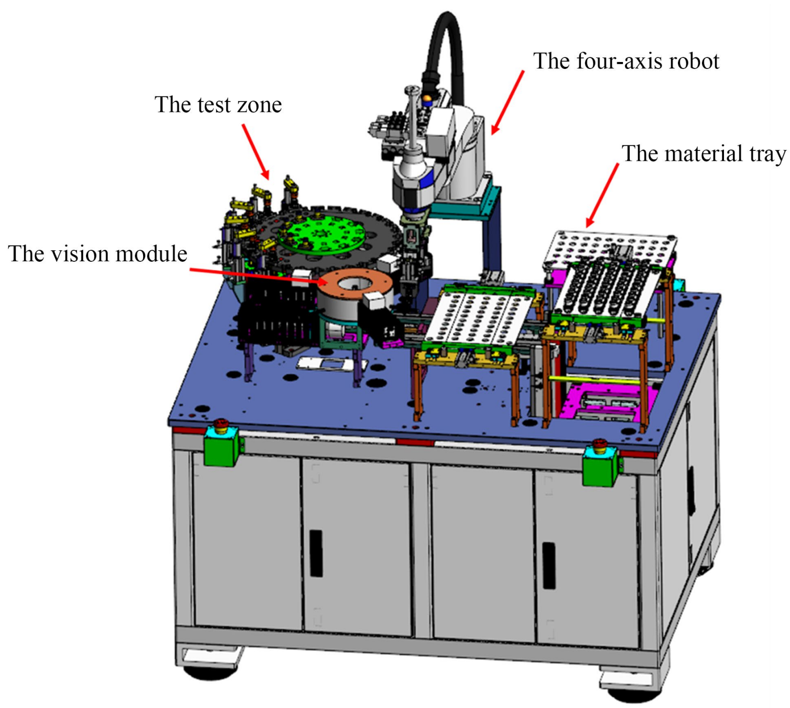

Figure 5. Schematic diagram of the overall structure of this system.

4. Results

4.1. Resistance Test between the Pins

Resistance between pins of identical samples was measured using standard resistance meters and automatic testing devices. The former adopted manual operation requiring two staff members for testing and data recording respectively, while the latter ran fully automatically.

Test results are summarized in Table 2. The resistance fluctuation reached 7 mΩ in automatic measurement, moderately higher than 2 mΩ obtained manually, yet both variations satisfied the permissible tolerance of ±0.5%. A single sample takes 12 seconds for automatic testing, marginally shorter than manual operation. Nevertheless, automatic testing only needs single-person operation and supports automatic data logging, presenting superior comprehensive performance.

Table 2. Resistance test data between the pins.

testing device		Resistance test data (Ω)					Testing fluctuations (mΩ)		Test time (s/sample)
resistance meter (manual)		1.037	1.036	1.037	1.037	1.036		2	15
		1.037	1.037	1.037	1.038	1.037			
Automatic testing device	Module 1	1.038	1.038	1.037	1.037	1.036	2	7	12
		1.037	1.036	1.036	1.036	1.036			
	Module 2	1.033	1.032	1.031	1.032	1.032	2		
		1.032	1.032	1.032	1.032	1.031			
	Module 3	1.032	1.032	1.032	1.032	1.033	2		
		1.031	1.031	1.031	1.031	1.032			
	Module 4	1.036	1.035	1.035	1.034	1.034	2		
		1.034	1.034	1.034	1.034	1.034			
	Module 5	1.034	1.033	1.035	1.035	1.035	2		
		1.034	1.034	1.034	1.034	1.034			
	Module 6	1.036	1.035	1.035	1.035	1.036	2		
		1.035	1.035	1.037	1.036	1.035			

4.2. Resistance Test of the Pin and the Housing

Resistance between electrode pins and housing of identical samples was measured by standard resistance meters and automatic test devices. The test was conducted continuously for one minute after power-up.

Experimental data are listed in Table 3. The resistance fluctuation was 14 MΩ in automatic measurement, moderately higher than 9 MΩ from manual testing. Both fluctuations complied with the allowable tolerance of ±5%. The single-sample test duration was 12 seconds for automatic detection, far shorter than 75 seconds of manual operation, which greatly improves testing efficiency.

Table 3. Resistance test data of the pin and the housing.

testing device	Resistance test data (MΩ)					Testing fluctuations (MΩ)	Test time (s/sample)
resistance meter (manual)	995	996	996	995	994	9	75
	994	992	990	988	987		

Continued

Automatic testing device	Module 1	1014	1011	1010	1011	1011	4	14	12
		1011	101	1012	1012	1011			
	Module 2	1010	1008	1008	1007	1007	5		
		1006	1005	1005	1006	1005			
	Module 3	1005	1004	1005	1005	1004	3		
		1002	1004	1004	1005	1004			
	Module 4	1007	1004	1003	1003	1004	4		
		1005	1004	1005	1005	1004			
	Module 5	1005	1004	1003	1003	1003	3		
		1002	1003	1003	1004	1004			
	Module 6	1001	1000	1000	1000	1000	1		
		1000	1001	1000	1001	1001			

5. Conclusions

The automated electrical performance testing system has been successfully developed and implemented in industrial production lines. Taking typical pyrotechnic devices as the object, it verifies that all process indicators satisfy the expected requirements. The quality data during the testing process is digitally collected and judged. Field production verification indicates that the automated testing scheme achieves fully unmanned operation, reducing operator demand from 2 to 1. Overall production efficiency is improved by a factor of over 6 compared to manual testing. In detail, the insulation resistance test cycle is reduced from 75 s per product to 12 s per product, and the low-resistance test cycle is reduced from 15 s per product to 12 s per product under unmanned operation.

Through the research and application of automated testing technology of electrical performance, the efficiency of electrical performance testing and the ability of process traceability have been significantly improved. This advancement enables fully unmanned operation of the testing process. It effectively improves the testing response capacity and quality control level of pyrotechnic devices. In addition, it satisfies the requirements for quantitative and refined management of such products.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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