Design and application of a new fast analysis software for satellite mechanical test data

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ABSTRACT

In order to solve the problem of consuming a lot of time in data analysis, condition formulation and summary report compilation of satellite mechanics test, a set of software for data analysis of satellite mechanics test was developed. Firstly, the system framework is constructed from the process of satellite vibration test. Then, the functions of the software are divided by sorting out each link of the test data analysis. In addition, according to the flow of data in the test, design the engineering data structure. Finally, combined with the characteristics of data interaction and convenient use of the software, a general module of the software is constructed.

Keywords: small satellites, mechanical test, data analysis, architecture design

1. INTRODUCTION

In recent years, with the proposal of rapid deployment tasks for the giant constellation[1], the design, production, and testing of satellites are facing higher quality and efficiency requirements brought about by mass production and short cycles. Especially in large-scale environmental experiments[2] of the entire satellite, how to quickly complete all experimental projects has become an urgent problem to be solved. In the mechanical vibration test of satellites[3], it is often necessary to develop acceptance level vibration test conditions[4] based on single machine test conditions, carrier telemetry data, or satellite rocket coupling analysis results, combined with onboard response data in the prediction level test, to ensure that the satellite can complete the assessment under reasonable conditions. In previous experiments, this stage required designers responsible for overall, subsystem, and even single machine development, as well as the supervising designers of mechanical experiments, to carefully analyze the data obtained from many mechanical sensors on the satellite based on the results of each vibration test. Through manual interpretation of each response curve, the final large-scale test conditions were formulated. This stage not only consumed a lot of manpower, but also the formulation of test conditions was slow, which hinders the improvement of the mechanical experiments' efficiency.

At present, the functions of data analysis for vibration or noise tests[5] are mostly integrated into data acquisition software, such as the commercial data acquisition and analysis software LMS Test. Lab[6] developed by Belgium's LMS company, Smartoffice software developed by Germany's M+P company[7], sound&vibration measurement A/S produced by Denmark's BK company, DHMA software produced by China's Donghua Testing Technology company[8], and DASP-MAS software developed by Beijing Oriental Noise and Vibration Research Institute, The experimental data collection is completed through the software acquisition module, and damping extraction[9], time-frequency data conversion, structural fundamental frequency and vibration mode identification are completed through the software post-processing module. The above data collection and analysis software is in an auxiliary position in satellite test data analysis. Generally, this type of software is used to obtain test frequency domain data, extract frequency domain curve peaks, review knock signals in the data, etc. Then, the designer analyzes the processed data to revise the full scale vibration test conditions of the satellite and compare the satellite data with the single machine condition level. The efficiency of satellite tests data analysis conducted in this way of work is low, and there are potential quality risks of human interpretation errors in the experiment.[1]

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In order to solve the above problems, the Beijing Institute of Satellite Environmental Engineering has developed the "BISEE Dynamic Test Data Analysis System", which can achieve functions such as data peak extraction, data consistency comparison, satellite test condition concavity[10], response prediction, and report preparation. However, the concavity functions of its test conditions is still in the early stages of exploration, and the formulated full scale vibration test conditions The generated test reports require significant modifications before they can be used, and the flexibility of the response indicates that there is still room for improvement. In addition, the overall satellite unit of the China Academy of Space Technology has developed a series of small programs using MATLAB for the concave part of satellite vibration test conditions. However, these programs are not convenient to use and the generated test conditions also need to be significantly modified before use. They are still in an auxiliary position for satellite test data analysis.

In summary, existing software for satellite test data analysis still lacks functionality in formulating vibration test conditions, generating test summary reports, and comparing test data consistency. This article starts from the satellite test process and combines the characteristics of satellite test data analysis to develop a fully functional and user-friendly software system for satellite mechanics test data analysis.

2. SYSTEM FRAMEWORK DESIGN

Due to the fact that the mechanical testing system is a software system developed for satellite vibration and noise testing, its various functional modules are developed based on characteristics of the satellite mechanical testing implementation. The implementation of satellite vibration tests includes three directions, each of which includes sine characteristic level tests——sine acceptance level tests——sine characteristic level tests——random prediction level tests——random acceptance level tests - sine characteristic level tests, etc. Different types of data analysis are required at different stages of the test implementation, for example, the data analysis after the first sine characteristic level test is used to develop the sine acceptance level test conditions, the data analysis after the random prediction level test is used to develop the random acceptance level test conditions, and the test data analysis after the second and third sine characteristic level tests are both used to determine whether the satellite has passed the acceptance level test assessment.

The underlying logic of the mechanical testing system framework has been formed based on process of the satellite vibration testing and the characteristics of data analysis: establishment of satellite operating conditions——import of test data——viewing of test data——formulation of test conditions——analysis of test data——formulation of test reports. Experimental data are the foundation for the operation of the entire mechanical experimental data analysis software. Through a single data import, data storage and management can be achieved. At the same time, all functional modules belong to the same system platform. By calling the experimental data through functional modules, the circulation of experimental data between each functional module can be achieved, reducing repeated management of experimental data and avoiding wasting of system memory resources, Improved the operational stability of the system software.

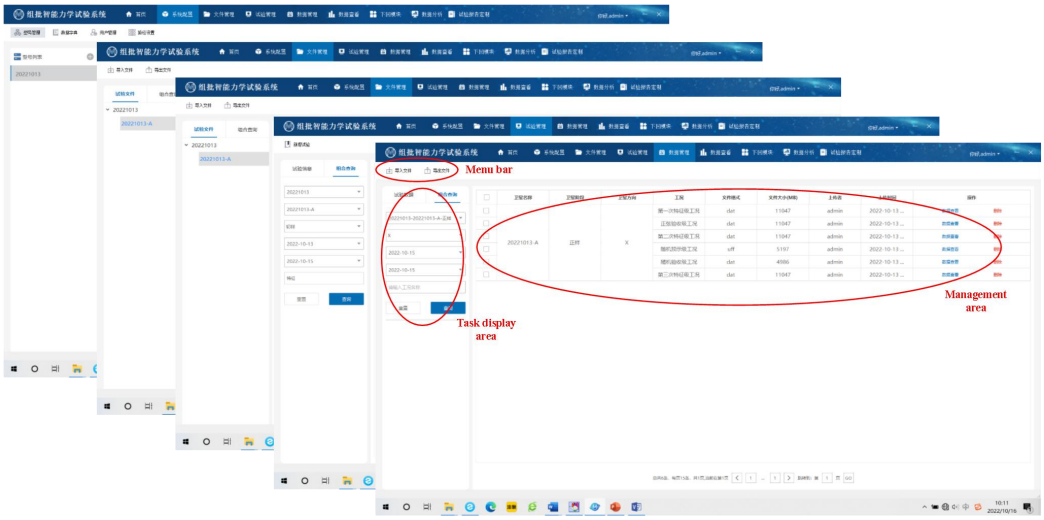

Figure 1. System Interface of Working Condition Configuration Area

The interface design and operation mode of the system configuration, file management, experimental management, data management, and other modules in the mechanical analysis software adopt a unified style. The running interface is shown in Figure 1: the menu bar and task display area control the implementation of each module's task, while the management area manages the established sub working conditions and tasks.

The interface design and operational methods of the data viewing, concave module, and data analysis modules in the mechanical analysis software adopt a unified style. The running interface is shown in Figure 2: the menu bar and task management area control the implementation of each module's task, while the display area displays specific data curves.

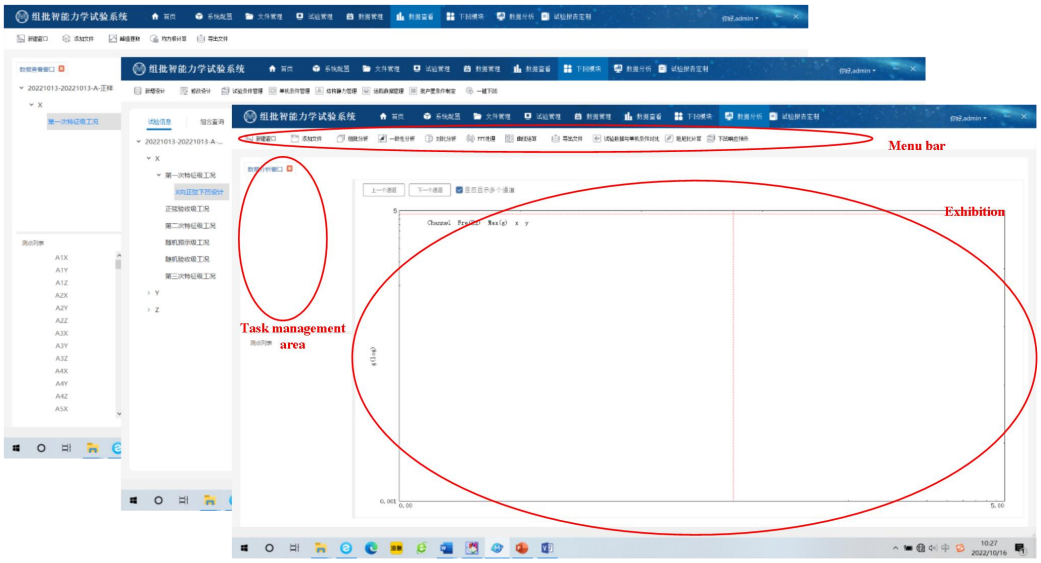

Figure 2. Data Analysis Area System Interface

3. FUNCTIONAL MODULE DIVISION

According to the general process of vibration test implementation, the mechanical test system is divided into eight main functional modules: system configuration, file management, test management, data management, data viewing, concave module, data analysis, and test report customization, as shown in Figure 3.

The main tasks of each functional module of the mechanical testing system are decomposed as follows:

1) System Configuration Module: Build the top-level task of the model satellite, manage the working condition name, file type, satellite stage, username and password required for the experiment.

2) File Management Module: Classify and manage the various files used in the experiment, such as Star Arrow interface files, test outlines, component test specifications, and other types of files.

3) Test Management Module: Used to construct information on all working conditions of satellite vibration tests, and to maintain, manage, and query it.

4) Data Management Module: Based on the working conditions established by the experimental management module, import and export corresponding data files, and be able to query data files.

5) Data Viewing Module: Capable of viewing experimental data, including data curve to display, peak information, root means square values information, and so on.

6) Concave Module: Capable of formulating acceptance level test conditions using concave algorithm based on sinusoidal feature level test data and random prediction level test data, while also correcting existing test conditions for batch production satellites.

7) Data Analysis Module: Through this module, the evaluation of test results is achieved, including consistency analysis of characteristic test data, comparative analysis of acceptance tests data and single machine test conditions. At the same time, it should have functions such as time-domain data processing, the dynamic response prediction, damping calculation, etc.

8) Test Report Customization Module: based on the imported test data, established test conditions, and data analysis results from the aforementioned functional modules, a satellite test result summary report is formed.

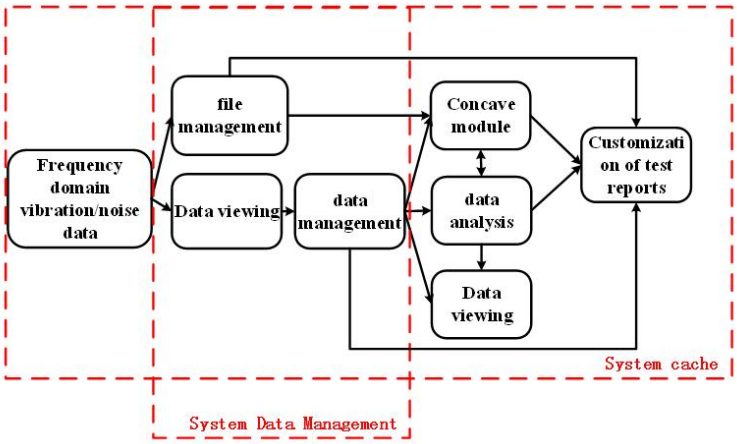

Figure 3. System Composition Logic Relationship Block Diagram

4. ENGINEERING DATA STRUCTURE DESIGN

The mechanical test data analysis software stores and manages the test data, test files, satellite system level test conditions, satellite single machine test conditions, launch telemetry data, and structural static test conditions, as shown in Figure 4.

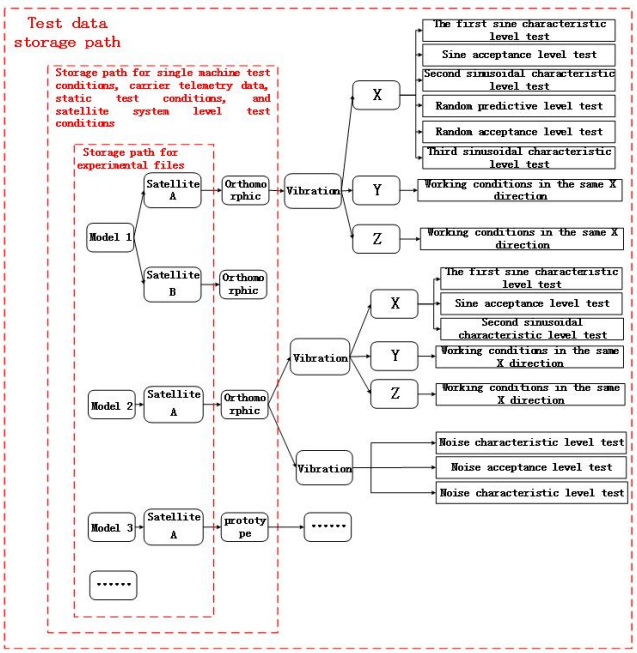

Figure 4. Test Data File Storage Path Block Diagram

From the above figure, it can be seen that the management of test files, test conditions (such as a single machine and carrier rocket's telemetry data), and test data is based on the model satellite. Among them, the management of test files is stored in the first level directory of the satellite, the management of test conditions is stored in the first level directory of the satellite stage, and all test data is stored in the first level directory of the test conditions. The storage path of test files, conditions, and data is closely related to their use in the experiment. The test files only vary depending on the satellite, and their use should be in the satellite level directory; For various test conditions and telemetry data management, due to the significant differences in the test conditions and telemetry data used by the same satellite at different stages, the use of test conditions and telemetry data at the first level of the satellite stage is more convenient; The experimental data is generated under different working conditions, so its storage naturally needs to be placed in the working condition level directory, as shown in Figure 5.

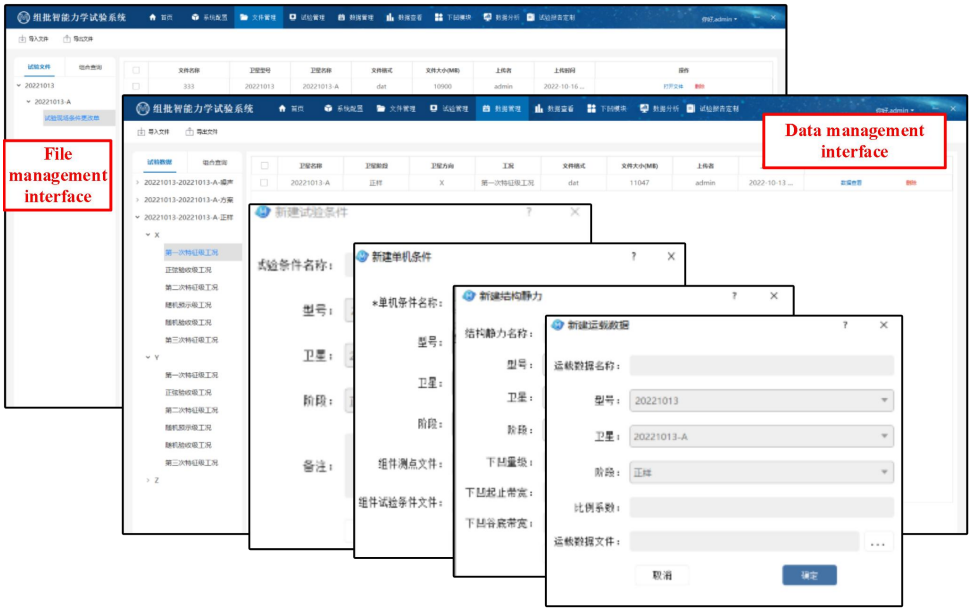

Figure 5. Test Data File Management Interface

5. UNIVERSAL MODULE DESIGN

5.1 Data File Interaction

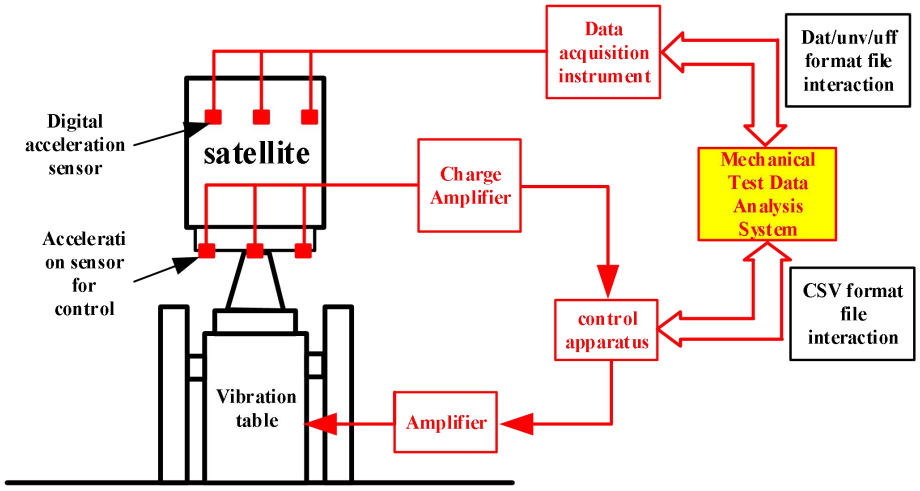

Figure 6. Schematic diagram of data exchange of software system in vibration test

The data interaction function is the cornerstone of the application of mechanical experimental data analysis systems. The system designed in this article can interact with data acquisition software such as LMS and DP. It can read the dat, unv, and uff universal format data files generated by the data acquisition software, and can also convert these three formats of data files to each other; In addition, the system can interact with vibration controllers such as LMS for test condition files, which can read CSV format files generated by the vibration controller and generate corresponding format files. Furthermore, through the mechanical test data analysis system, the interconnection between the data collection subsystem and the vibration control subsystem in vibration testing is achieved, laying the foundation for the implementation of intelligent vibration testing, as shown in Figure 6.

There are significant differences between dat, unv, and uff universal format data files. To achieve mutual conversion between the three, it is necessary to have a deep understanding of the three formats of data files. Below, taking the uff universal format file as an example, this software can recognize uff universal format files, as shown in Figure 7.

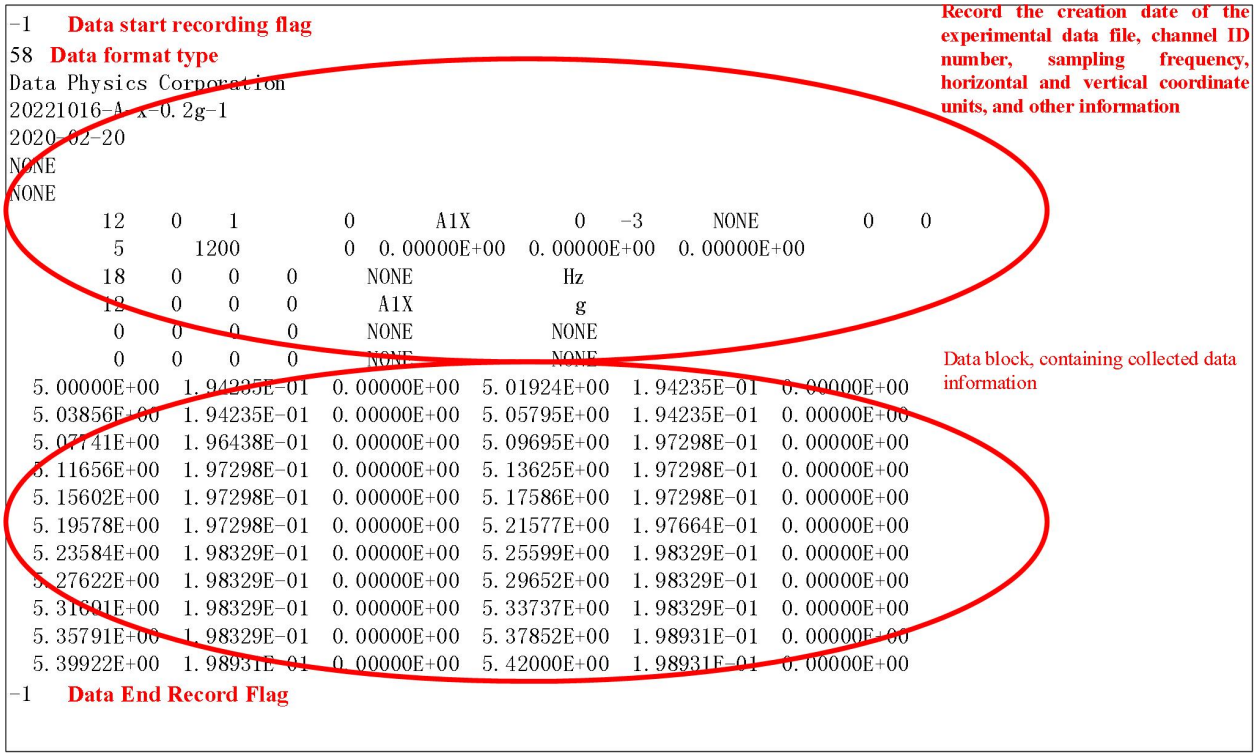

Figure 7. Schematic diagram of UFF format file parsing

In order to achieve interconnectivity between mechanical test data analysis software and vibration control software, while also considering the format of test conditions in the satellite rocket interface file, an analysis was conducted on the mutual conversion of test condition formats. Taking the sine test conditions as an example, Table 1 shows the test condition formats recognized by the Star Arrow interface file and LMS vibration control instrument. Based on the CSV file, compatible design of the two is carried out to a CSV file recognition and export function with two formats, as shown in Figure 8.

Table 1. Satellite Sinusoidal Vibration Test Conditions

Star Arrow Interface File		LMS Vibration Control Software		
Frequency range *(Hz)*	Vibration amplitude	Frequency	level	unit
5 ~ 8	3.1 *mm*	5	3.1	*mm*
8 ~ 100	0.8 *g*	8	0.8	*g*
		100	0.8	*g*

Satellite and Rocket Interface File Recognition Format			
Starting frequency	cut-off frequency	amplitude	unit
5	8	3.1	mm
8	100	0.8	g

LMS control software recognition format		
frequency	amplitude	unit
5	3.1	mm
8	0.8	g
100	0.8	g

Figure 8. Schematic Diagram of UFF Format File Parsing

5.2 Design of 2D data display interface

The mechanical test data analysis software needs to display the test data curves in the data viewing, concave module, and data analysis module. This paper designs a two-dimensional data display interface based on the data characteristics and experimental requirements, as shown in Figure 9.

Figure 9. 2D Data Display Interface

a) The logarithmic coordinate display function often uses frequency domain data for analysis in vibration and noise tests. Test data are generally viewed and analyzed in logarithmic coordinates, so the curve display window is designed in the default logarithmic coordinate form;

b) The cursor floating line displays the information of curve data points, which are convenient for querying data in the form of a cursor floating line. When the mouse touches the curve data points, the corresponding horizontal and vertical axes are displayed on their own;

c) Display of curve peak value information. In view of the characteristics of data curve peak value in the process of traditional test conditions development, the curve peak value information is displayed in the legend, and the root mean square value information is displayed for the power spectral density curve;

d) The function of adding marker lines is required during the traditional experimental condition formulation process to facilitate the viewing of the data level. Therefore, horizontal and vertical marker lines have been designed in the curve display interface, which can be moved with the mouse or deleted with the right click;

e) The data export function can export the curves currently displayed in the interface in the form of images or data formats such as unv, uff, dat, CSV, etc;

f) The curve scaling and display function of any frequency band curve can be used to zoom in and out of the curve through the coordinate axis scaling function, in order to clearly view the curve features, and limit the curve information of interest by setting the frequency range of the horizontal axis;

g) The data comparison function can compare and analyze different or the same measurement point curves under any working condition, as well as different measurement point curves under the same working condition, in the same display window.

6. CONCLUSION

This article has developed a satellite mechanics experimental data analysis software, which greatly reduces the workload of the test supervisor designer in the entire satellite experimental data analysis process, shortens the time for formulating experimental conditions and preparing experimental summary reports, enhances the reliability of experimental condition formulation and experimental data analysis, and lays a solid foundation for satellite intelligent testing.

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