The Development of High-Precision & High-Speed Synchronous Data Acquisition System in Vacuum-Thermal Test

Jingyi Shao¹*, Juan Ning¹
¹Beijing Institute of Spacecraft Environment Engineering, Beijing, China
*Corresponding author: Jingyue_yy@163.com

Abstract. The Vacuum-Thermal test is an important test to verify the correctness of the thermal design and ensure its long-term reliable operation during the development of the spacecraft. At present, the temperature measurement in the Vacuum-Thermal Test mostly adopts the serial mode to complete the data acquisition of the large data volume temperature sensor. This method balances performance and costs well. However, in some special circumstances, it cannot accurately reflect the instantaneous temperature of the test piece. Aiming at this problem, a high-precision and high-speed fully parallel data acquisition system is designed. Based on the accuracy of the original temperature data acquisition, high-speed synchronization technology is used to accurately acquire the transient temperature data of the spacecraft to verify the transient heat of the spacecraft. Features provide a data foundation.

1. Introduction
In the thermal vacuum test, the data acquisition of the test piece is a very important part of the test, the basis of temperature control, and the basis for judging the thermal characteristics of the test piece under the cold black background of space [1-3].

At present, data acquisition tasks are generally accomplished by means of a digital multimeter with multiple multiplex switches in large vacuum thermal tests, because of there are more measurement channels. This measurement method effectively solves multi-channel data acquisition and effectively controls the cost [3]. However, the measurement time increases with the number of channels because the number of measurement units and channels are measured serially. It cannot effectively measure the instantaneous temperature characteristics of the test piece, and the temperature control increases the difficulty. At the same time, the digital multimeter and the multiplexer switch use the relay to realize the measurement signal switching and the measurement channel switching function, thereby increasing the probability of equipment failure.

Based on the high-precision synchronous high-speed measurement board, this paper designs a vacuum-thermal test fast data acquisition system, which can complete the data collection of large vacuum-thermal test and improve the reliability of the system [5].

2. Analysis of current status of data acquisition in the vacuum-thermal test
At present, there are two main methods of data collection commonly used in the vacuum-thermal tests:

- High-precision digital multimeters: used in medium and large thermal vacuum tests;
- Dedicated analogy input modules (PLC modules, etc.): used for small thermal vacuum tests.

Both data acquisition methods have their own advantages.
Because it has more temperature measurement points and higher measurement accuracy, the medium or large thermal vacuum tests generally use custom thermocouples as temperature sensors, using high-precision digital multimeters with multi-way switches for data acquisition. The software in the host computer is used for remote control, fitting calculation, data recording and other functions. The data acquisition provides feedback point temperature for the temperature control software, and the feedback point can be flexibly adjusted during the test. However, this method requires the host computer to drive the instrument through the communication protocol, and the speed is slow. Generally, there is only one or several measuring units. In the case of a large number of measurement channels, data acquisition takes a long time to complete a cycle of temperature measurement. This method cannot accurately reflect the temperature characteristics of the test piece at the current moment, in the case of a rapid temperature change. Moreover, in a complicated network environment, the disconnection of the network cable or the congestion of the network is prone to occur, so that the control command of the upper computer cannot be sent to the instrument, resulting in abnormal control.

Because it has fewer measurement channels and requires less measurement accuracy, the small thermal vacuum test generally uses PT100 as the temperature sensor, and uses RTD module of PLC to complete data acquisition. This method is faster, but the acquisition accuracy is lower. The general AD conversion accuracy is 12 bits, which is only used for data acquisition of temperature sensors such as thermal resistors. It cannot meet the requirements of small signal data acquisition such as thermocouples. Moreover, the number of channels in this method is limited, which is not conducive to channel expansion, and has many limitations, and the application range is small in the vacuum vacuum-thermal test.

Therefore, high-speed and high-precision data acquisition needs to be introduced into the vacuum-thermal test to meet the monitoring of transient temperature conditions of complex test pieces and improve the test capability of vacuum -thermal test.

3. High-precision & High-speed Data Acquisition System

3.1. Requirement Analysis

The data acquisition of vacuum-thermal test generally includes one or more of the above signal types, and the number of measurement points varies from tens to hundreds of points.

There are two main types of signals for commonly used sensors in the data acquisition of vacuum-thermal test:

a. Thermocouple / heat flow meter: the measured value varies from -20mV to +20mV, measured by single wire lead method;

b. Pt100 platinum resistance: The measured value varies from 10 to 200 Ω, and adopts four-wire lead method.

The data acquisition of vacuum-thermal test accuracy and resolution requirements:

a) Data acquisition AD conversion accuracy is not less than 24 bits, or six and a half effective collection of numbers;

b) Temperature data acquisition accuracy is not less than ±0.5 °C.

The data acquisition of vacuum-thermal test speed and synchronization requirements:

a) The data acquisition sampling speed is not lower than 1 Hz, and the sampling speed is adjustable;

b) Data acquisition of each channel can be completed simultaneously, and the number of channels can be expanded without affecting the acquisition speed.

At the same time, the system also needs to display and store data in real time when data acquisition is completed, and share data through the measurement and control network. And the system should have strong adaptability and versatility, and the measurement system can be configured according to the specific needs of the test.
3.2. Structure of the System

The system consists of measuring sensors, distribution boxes, reference points, PXIe acquisition boards, computers, servers, etc. The data structure of the data system is shown in Figure 1.

The measurement signal is led out from the vacuum vessel through the wall plug to the outside of the container, and the measuring instrument is connected through the junction box. Then, the data is transmitted to the main control computer through the Ethernet to perform data processing, display, storage and the like.

3.3. Structure of the Hardware

The chassis is PXIe-1062Q, and the embedded controller uses PXIe-8135, which can support up to 7 PXIe boards to perform data acquisition [6].

The data acquisition board uses PXIe-4353 and PXIe-4357 to measure the thermocouple signal and platinum resistance signal respectively. The PXIe-4353 has 32 thermocouple acquisition channels with 24-bit sampling accuracy, a maximum sampling rate of 90S/s/channel, a high-resolution sampling rate of 1S/s/channel, and a voltage acquisition range of ±80mV. The PXIe-4357 has 20 RTD acquisition channels that support PT100 or PT1000 resistance acquisition, 24-bit sampling accuracy, maximum sampling speed of 100S/s/channel, and high-resolution sampling speed of 1S/s/channel [7-8].

In the vacuum heat test, PXIe-4353 and PXIe-4357 are used for data acquisition at the same time. The sensor signals acquire date acquisition by sub-link box and term block to access the acquisition unit. And the data perform fitting in the controller, that uses a PT100 to calculate the reference point temperature, then the thermocouple compensation voltage has been obtained. Finally, the actual measured value of the thermocouple with the compensation voltage to calculate the actual temperature. The controller connects to the client via Ethernet for communication and data transfer. During the data acquisition process, the Ethernet is accidentally disconnected, and the controller can operate...
independently without affecting data acquisition and improve the reliability of the data acquisition system.

4. **High speed data acquisition software**

The high-speed data acquisition software is independent in function and is responsible for measuring the instantaneous temperature of the test piece. It can measure, process and display various signals such as platinum resistance, thermocouple and heat-flow meter.

4.1. **Development Environment**

The software development platform uses LabVIEW, the system operation platform is Windows 7 Professional Edition, and the system operation network platform is a computer network platform for vacuum thermal test measurement and heat flow simulation system.

LabVIEW software is a virtual instrument development tool introduced by National Instruments. It is widely used in industrial automation, instrument control, data acquisition and processing, and is unified with hardware manufacturers. The hardware driver configuration is simple, programming is convenient, and software development and debugging cycles are shortened [9].

4.2 **Module of Data Acquisition**

The measurement software sends commands through the LAN interface to drive the digital measuring instrument. Through the PXIe bus, it can read all channel voltages and resistance values simultaneously.

The temperature value of the measuring points is calculated by the fitting formula. Data are displayed in tabular form on the software interface, and it has been stored separately on the local computer and server. The software flow chart is shown below.

![Software flow chart](image)

**Figure 3. Software flow chart**

The original data acquisition module performs data storage after each cycle of data acquisition and fitting, and the method does not have much influence on the collection task of low sampling rate. However, this method cannot fully utilize system resources. When the sampling rate is greatly
improved and the multi-channel synchronous acquisition task is, the file storage speed may have a certain degree of influence on the sampling period. The redesigned acquisition unit uses dual-thread work (As shown in the figure). One of the threads puts the data in the capture card buffer into a circular queue that is applied to the system in advance, and another thread takes the data in the circular queue and writes it to the local file. Each thread independently occupies one CPU core for accurate sampling timing. This method can effectively utilize system resources and is suitable for high sampling rate and multi-channel synchronous acquisition.

![Dual-thread working diagram](image)

**Figure 4. Dual-thread working diagram**

5. Equations and mathematics

The system is now deployed in multiple equipments. Temperature data acquisition is shown in Figure 5. The acquisition speed is significantly better than the original data acquisition system. The sampling frequency is set to 20Hz (that is, the sampling period is 50ms), which can accurately measure the rapidly changing temperature and meet the needs of high-speed data acquisition systems.

![Running Result](image)

**Figure 5. Running Result**

6. Conclusion

As an important sub-system of vacuum heat test, the data acquisition system has large number of measurement data points, various test signals, and high data accuracy requirements. This paper introduces the application of PXIe high-speed data acquisition system in vacuum heat test. The method satisfies the requirements of the data acquisition system and simultaneously realizes the measurement of the instantaneous temperature of the tested test piece, which can more accurately
reflect the thermal characteristics of the time. It also lays a good foundation for better temperature control. The system has been tested several times by multiple devices, the system is stable and reliable, and the measurement data is accurate.

References
[1] David G Satellite Thermal Control Handbook [G], 1994
[2] Huang Bengcheng, Ma Youli, Space Environment Test Technology of Spacecraft[M], Beijing: National Defense Industry Press, 2002
[3] YAN Shaoguang, MEN Yu, ZHOU Binwen, WU Dajun, HAN Wei, ZHENG Lide, Design and Implementation of Database for Spacecraft Vacuum Thermal Test [J], Spacecraft Environment Engineering, 2006 23(4):201-204
[4] Wu Dajun, Application of Keithley 2750 to the Measurement System in Vacuum Thermal Test [J]. Spacecraft Environment Engineering, 2006, 23, (2): 115-118
[5] Huang Bencheng, Tong Jingyu, The space environment engineering[M], China Science and Technology Press, 2010
[6] PXI Temperature Input Module Manual [X], National Instruments Corporation, 2017
[7] NI PXIe-4357 Specifications [X], National Instruments Corporation, 2012
[8] NI PXIe-4353 Specifications [X], National Instruments Corporation, 2012
[9] Wu Hui, Design of General Data Acquisition System Based on PXI and LabVIEW [J], Computer Measurement & Control, 2015 23(5): 1686-1688
[10] Song Ming, LabVIEW programming details[M], Beijing: Publishing House of Electronics Industry, 2017