Development of Thin Film Thermocouple Test System for Transient Temperature Measurement

Zhu Xi*, An Wanqing, Liu Chang, Yang Xiaoyuan, Su Xinming, Zhou Yan, Li Zhenwei, Liu Zeyuan

Beijing Institute of Spacecraft Environment Engineering, Beijing, 100094, China

*Corresponding author’s e-mail: 525891876@qq.com

Abstract. In order to achieve accurate temperature measurement in a fast temperature change environment, a set of thin film thermocouple test system for transient temperature measurement is designed and developed. The system consists of cold junction compensation and data collector. The temperature of the film thermocouple can be obtained in real time through the upper acquisition software. The hardware composition and software design of the thin film thermocouple test system are given. The data acquisition terminal and coordinator program are designed to control the temperature signal of the MAX31855 to collect the sensor, realizing the real-time transmission of temperature data between the sensor and the computer. In order to verify the actual application effect of the system, the matching, stability and reliability of the temperature acquisition system and monitoring software, the FLUKE-9144 dry calibration furnace was selected as the heat source for the temperature test. The test results show that the system has fast acquisition speed, high measurement accuracy and good temperature stability.

1. Introduction

With the continuous advancement of equipment technology in China, it is increasingly necessary to obtain accurate physical parameters of products or environments to correct simulation models or to clarify design boundaries. At present, how to measure instantaneous temperature changes in an environment above 1000 °C is still a difficult problem in the development of equipment. For example, the instantaneous measurement of the barrel temperature of the projectile launch, the temperature measurement of the inner wall of the cylinder of the internal combustion engine, and the temperature measurement of the thermal protection structure of the high-speed aircraft require that the high temperature sensor be small in size, without damaging the test piece or affecting the environment to be tested. For explosive temperature measurement, rocket engine tail flame temperature measurement, combustion chamber gas temperature measurement, etc., the heat is rapidly released, and the temperature of the measured target is instantly increased by several hundred degrees (usually in the order of milliseconds or even microseconds), which requires The temperature sensor has excellent dynamic response.
In order to adapt to the high temperature environment, the traditional contact type high temperature sensor usually uses the armor method to protect the sensor itself, which not only increases the volume of the sensor, but also changes the heat capacity of the sensor, and cannot accurately detect the instantaneous temperature change. The optical-based non-contact temperature measurement method is not only inferior in accuracy, but also cannot be applied to temperature measurement inside a closed structure. A thin film thermocouple refers to a temperature sensor that uses the Seebeck effect to measure temperature and has a hot junction thickness of only micrometers. The high temperature sensor based on thin film thermocouple technology has the characteristics of small volume, small heat capacity, short thermal response time, high precision and high sensitivity, and it has small interference and damage to the measured target and test environment, and is suitable for narrow space and difficult installation. When the temperature changes instantaneously. This paper introduces the composition of the film thermocouple test system, and develops the film thermocouple upper acquisition software. Finally, the system is tested. The test results show that the system has fast acquisition speed, high measurement accuracy and good temperature stability.

2. Test system components

2.1. Cold junction compensation design

The thermocouple output thermoelectric potential reflects the operating temperature relative to the reference terminal, while the purpose of the temperature measurement is to measure the operating temperature at 0 °C. Therefore, only when the reference end of the thermocouple is placed in the ice water mixture, the temperature of the reference end can be kept at 0 °C regardless of the ambient temperature. At this time, the thermoelectric potential of the thermocouple corresponds to the temperature of the standard index table. It is the temperature of the measuring point (ie the working end). In practical engineering applications, it is difficult to ensure that the reference end of the thermocouple is always at 0 °C, which is the reason and significance of the thermocouple compensation for the cold junction during the temperature measurement process.

In this paper, the MAX31855 chip is used to collect the cold junction temperature. The MAX31855 is a thermocouple to digital output converter from Maxim, USA. The chip has a 14-bit analog-to-digital converter (ADC). It has cold junction compensation and correction for external thermocouples. Maxim offers a range of models for different types of thermocouples such as B, K, and N. Each model is optimized and tuned for the specific thermocouple type. The film thermocouple sensor of this system belongs to type B thermocouple, and the model is MAX31855KASA+ chip. In this system, its function is to perform cold junction compensation and analog-to-digital conversion of the film thermocouple in the sensing temperature designed by the project. Figure 2 shows the pin configuration of the MAX31855, and Figure 3 shows the internal structure of the MAX31855.
The MAX31855 includes a signal conditioning hardware circuit that adjusts the weak thermocouple signal to match the input to the analog-to-digital converter ADC input channel. Before the electrical signal of the thermocouple is converted to its corresponding temperature value, the cold junction compensation of the thermocouple is required. In order to ensure that the temperature value obtained after the conversion is the actual working terminal temperature. For a standard K-type thermocouple, the Seebeck coefficient is approximately 41 μV/°C, and the thermocouple output characteristics are approximated according to equation (1).

\[ V_{OUT} = (41.27\mu V/°C) \times (T_R - T_{AMB}) \]  

In the formula, \( V_{OUT} \) is the thermocouple bipolar output voltage; \( T_R \) is the thermocouple working terminal temperature; \( T_{AMB} \) is the thermocouple reference terminal temperature.

The MAX31855 performs cold junction compensation and correction of external thermocouples by sensing the temperature at the reference junction. The die temperature inside the chip is first detected by the chip internal temperature sensor. The output voltage of the external thermocouple is then measured by an analog-to-digital converter ADC and converted to the equivalent temperature of the thermocouple before compensation. By the superposition of this value and the internal die temperature of the chip, the operating temperature of the external thermocouple based on 0 °C is calculated. It can be seen from the above that when applying the MAX31855 in engineering, the reference end of the external thermocouple should be placed as close as possible to the MAX31855 chip, so that the temperature is as close as possible to the die temperature of the chip to reduce the reference temperature measurement error.

2.2. Data collector design

The data acquisition terminal device function backplane is mainly composed of CC2530 pin interface circuit, indicator circuit, MAX31855 thermocouple to digital output converter, reset circuit and power supply circuit. Figure 3 is a schematic diagram of the function of the data acquisition terminal function of the thin film thermocouple sensor temperature test system designed for this project. The indicator circuit is used to indicate the working state of the thermocouple signal acquisition terminal. The function of the MAX31855 thermocouple to digital output converter is to convert the mV-class weak signal of the thermocouple into the thermocouple temperature signal before compensation, and collect the thermocouple cold junction temperature signal and fault diagnosis of the thin film thermocouple. The power supply circuit uses the HT7533 high-precision voltage regulator chip to convert the 3.7V power supply of the lithium battery into the 3.3V power supply voltage required by the system, and at the same time filter out the power supply interference signal. The physical data diagram of the data acquisition function of the film thermocouple sensor temperature test system is shown in Figure 4.
3. PC software design

3.1. Software overall structure design
The software is modularized for the functions and usage requirements of the system. The designed modules mainly include: user information module, data monitoring module, data processing module and database part. The software structure diagram is shown in Figure 5.

![Software Structure Diagram](image)

Figure 5. Sensor temperature test system software structure diagram

The PC software uses the Visual Studio development tools to apply the WPF user interface framework application developed in C# language. The PC software adopts a modular design and has a good human-computer interaction interface. The software implements the functions of receiving, storing and deleting the data transmitted by the coordinator, and displays the measured temperature data in real time in both digital and graphical forms. For non-standard thermocouples, the software can manually set the Seebeck coefficient, and can set the upper and lower limits of the cold end and hot end. When the temperature exceeds the upper limit or lower than the lower limit, the software alarm light flashes and the alarm sound is played. The crystal report control is used to realize the export of multiple formats of sensors to measure temperature data.

3.2. Data Monitoring Module Design
The data monitoring module is the core module of the application software system, and provides the main functions realized by the system. The data monitoring interface is shown in Figure 6. It realizes functions such as data acquisition and processing, data display, database access, temperature alarm, fault alarm, Seebeck coefficient setting, and serial port automatic retrieval.

1) Data acquisition is to read the data of the serial port buffer through the serial port of the system. After the data is separated by a certain algorithm, the actual cold end and hot end temperature data sets are obtained.

2) The data display is to draw the data curve in real time by embedding the ZedGraph control in the Win Form application in the WPF framework application. At the same time, the temperature data of the current sensor is displayed in real time through the software text box control.
3) Database access is to save the data read by the serial port and additional information to the monitoring database.

4) The Seebeck coefficient setting is to set the Seebeck coefficient of the self-sensing sensor thermocouple through the text box input control. After the software reads the Seebeck coefficient set by the user, the data collected by the serial buffer is calculated. The corresponding sensor is measured to measure the temperature.

Figure 6. Data monitoring module software flow chart

3.3. Data processing module design
The data processing module provides users with functions such as data query, data deletion, and report generation. The data query function uses the conditional query method to perform a secondary query. The data processing module software flow chart is shown in Figure 7. The data query interface is shown in Figure 8. The software uses the Crystal Report Control to implement a variety of format file export sensor measurement temperature data.

Figure 7. Software flow chart of data processing module

Figure 8. Data query interface

4. Test results and analysis
In order to verify the practical application effect of the developed film thermocouple temperature sensor, the matching, stability and reliability of the temperature acquisition system and monitoring
software, the FLUKE-9144 dry calibration furnace was selected as the heat source for the temperature test, and the calibration furnace was set up. The temperatures were 100 °C, 200 °C, 300 °C and 400 °C, respectively. Through the data processing of the monitoring software, the temperature measurement curve of the temperature test system is shown in Fig. 9. From the four sets of temperature measurement curves, it can be seen that the thin film thermocouple sensor can quickly respond to temperature changes, and the signal is sent to the monitoring software for processing and display in time through the temperature measurement system. The temperature measurement system has good temperature stability and temperature measurement. The error does not exceed ±0.5 °C.

![Figure 9. Temperature measurement system test curve](image)

5. Conclusions
This paper introduces a thin film thermocouple test system for transient temperature measurement, which is studied from the aspects of system composition and upper acquisition software. The cold junction compensation, data acquisition terminal and coordinator program of the acquisition system are designed to realize the real-time transmission of temperature data between the sensor and the computer. The system PC software based on C/S architecture has been developed, which has the advantage of fast response speed. The system has the advantages of fast acquisition speed, high measurement accuracy and good temperature stability. It can meet the application of gun barrel temperature measurement, cylinder inner wall temperature measurement and high-speed aircraft thermal protection structure temperature measurement.

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