Application of laser displacement measurement system in thermal test of aircraft

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Abstract: At present, there is no research on nanosecond displacement measurement technology for spacecraft thermal test in China. Firstly, the principle of laser displacement sensor measurement is introduced. A system of hardware and software design and implementation was designed. Finally, a set of test system is built to verify the application of laser displacement meter in the spacecraft vacuum thermal test displacement measurement system. The experimental results and data analysis show that the laser displacement meter can meet the nanosecond displacement measurement requirements of spacecraft in vacuum and low temperature environment.

1. Introduction
China's space launch missions have been increasing year by year, especially in the deep space exploration and space shuttle aircraft model mission development process. The spacecraft and its components will encounter a high thermal environment with a maximum heat flux of 420 solar constants and a maximum temperature of 1600°C. In this environment, the surface material or structure of the spacecraft will produce displacement changes. At present, the displacement measurement in thermal test of spacecraft at 1600°C mainly adopts the contact displacement measurement method, which mainly includes the displacement measurement method of inductance and capacitance. The principle of the displacement measurement method of inductance and capacitance is mainly to measure the displacement by converting the displacement signal into the corresponding electrical signal. The manufacturing technology, use method, safety, reliability and life of the non-contact measuring sensor have not been mastered. In this paper, the principle of laser displacement meter is analyzed, measured and used, and finally a set of measurement system is designed and successfully applied to the thermal test of a spacecraft. The problem of displacement measurement in the thermal test of spacecraft at ultra high temperature is solved.

2. Principle of displacement sensor measurement
Displacement measurement methods include contact type and non-contact type. The non-contact method has the advantage of full-field measurement, and the laser triangulation method is a non-contact displacement measurement method. The principle is that the optical signal carrying the information of displacement is converted into an electrical signal, which is recognized and processed by the computer. Since the incident ray and reflected ray formed a triangle during the sensor measurement, it is called the principle of optical triangulation. Figure 1 is a typical schematic diagram of direct laser triangulation. The optical path system is mainly composed of a semiconductor laser, a
converging lens, a receiving lens, a CMOS optical receiving element and a subsequent signal processing circuit[1].

Figure 1. Principle of direct beam triangulation laser measurement

A semiconductor laser is used to beam a laser onto a target. The reflected light of the target object will be focused on the receiving lens, and the image will be on the light receiving element. When the distance changes, the reflected Angle of the focus changes, and the imaging position on the optical receiver also changes[2]. Since the change of imaging position on the optical receiving element varies with the amount of movement of the target, the change of imaging position can be read and measured as the amount of movement of the target.

The laser sensor use a "laser" with the straightness of the emitting element. Because light spots are visible, it is very easy to adjust or detect the position of a particular optical axis. In addition, light does not diffuse, so you can install it without having to worry about light deflection, etc.

The laser displacement sensor is shown in figure 2. The displacement sensor is based on the principle of triangulation laser measurement. By changing the distance from the target, the focus position on the detection element CMOS is changed[3]. The displacement information is output by analogy or digital quantity. The displacement of the object is measured by the software of the upper computer.

Figure 2. Shape diagram of laser displacement sensor

As shown in the picture, the laser is illuminated to the target by a semiconductor laser. The reflected light of the target object is focused on the receiving head and imprinted on the receiving element. Once the distance changes, the reflected Angle of the focus will also change, and the imaging position on the optical receiver will also change[4]. Since the change of imaging position on the optical receiving element varies with the amount of movement of the target, the change of imaging position can be read and measured as the amount of movement of the target.

3. System design and development

3.1. Realize the function
Measuring range: 0-200mm;
Absolute error: Better than ±50um;
Working distance: ≥300mm;
3.2. System design

This system consists of laser displacement measuring system, including laser displacement device, amplification unit, communication unit, signal transmission line, 12V power supply line, switch, computer and upper software. Its structural diagram is shown in figure 3.

![Figure 3. Laser displacement measurement system of figure](image)

The laser displacement meter amplification unit is connected to the laser displacement sensor, which supplies power to the laser displacement meter and outputs the output signal in the form of analogy or digital quantity. The amplifier unit is mounted with the laser displacement sensor probe in an airtight box and placed in a vacuum container.

The laser displacement meter communication unit module supports Ethernet communication. The signal of laser displacement meter is transferred to PC through Ethernet after conversion. The upper computer software collects the signal of laser bit shifting and converts it into displacement. The communication unit and power supply module are installed in the instrument box and placed outside the container.

3.3. System stability design

The laser displacement meter should be used in a vacuum container in a vacuum environment. Because the laser displacement sensor cannot withstand the vacuum. Moreover, the operating temperature range is between -10 and 50 degrees Celsius, so low temperature cannot be tolerated. Therefore, the laser displacement meter and amplifier need to be heat preservation and vacuum resistant treatment.

The laser displacement sensor and amplifier are installed in a closed rectangular box with transparent glass flange, from which the laser displacement meter measurement beam irradiates to the measured object. A connecting plug is provided on the box to output the power supply and output signal of the displacement meter from the plug.

![Figure 4. Laser displacement meter tooling](image)

The 5 sides of the closed box are made of 304 stainless steel. The wall thickness is 10mm, and the external size of the box is about 130*110*110mm. The detailed dimensions of the box are designed in detail and the comprehensive strength calculated before the actual work.

Paste the heating sheet outside the rectangular box. The size of the heating plate is selected according to the shape size, and the heating plate is arranged on the outer surface of the rectangular box. The heating plates are connected in series to form a circuit, and the corresponding thermocouple
for each heat preservation circuit is 1. In other words, each heat preservation circuit USES 1 temperature measuring point, 1 adjustable power supply and 1 set of heating plates, and each circuit is independent. The temperature signal returned by the thermocouple is fed into the measurement and control software system. The heating current value is calculated by the heat preservation program in the software system, then the specified current value is output to the adjustable power supply, and the heating plate is energized and heated.

In addition, after the heating plate is pasted, wrap the rectangular box with multiple layers. Combined with electric heating, the temperature of the rectangular box in low temperature environment can be maintained at 20±2°C.

For temperature control, the current of electric heating plate should be less than 1A. Usually used between 0.5-0.8a, the current is too large, it is easy to heat up and burn the heating plate. The stainless steel box with the laser displacement meter is supported by a carbon fiber tripod.

3.4. Software design
The displacement meter communicates with the host computer via Ethernet. Design upper software, can start stop monitoring displacement, set displacement zero. Test the positive and negative displacement of the measured object. And save the test values as required. Upper computer software interface simple operation, reliable communication.

4. Test and data analysis
4.1. Test environment
The thermal structure of C/C, C/SiC high temperature composite material was designed as the test piece. The working principle of the thermal test system is shown in figure 7.
In terms of control, the infrared lamp is used as the heating element of the radiant heating system. The SCR power control system provides power to the infrared array and controls the heating temperature. The whole test system consists of transformer, circuit breaker, history control cabinet, temperature sensor and temperature controller.

4.2. Test result

4.3. Analysis of test results

1. Surface material, color, roughness, inclination, optical properties, etc. The measurement accuracy will be affected. Spot center location is not used to ensure the accuracy of displacement measurement.

2. The laser displacement sensor mainly USES the light scattered from the object surface for measurement, so the roughness of measurement is uniform and the error is small when the object is close to the ideal diffuse reflector.

3. When the measured surface is tilted, the laser displacement sensor will produce a large measurement error.

4. The stability displacement of the carbon fiber tripod structure of the measurement system under vacuum and low temperature environment leads to the measurement error.
5. Conclusion

Firstly, the principle of laser displacement meter is analyzed theoretically. Then a displacement measurement system for spacecraft thermal test is proposed. The hardware and stability of the system were designed, and its performance was verified by vacuum and low temperature test[5]. The results show that the laser displacement measurement system can meet the requirements of spacecraft thermal test. The laser displacement meter is treated with heat preservation and pressure protection. The displacement measurement technique under vacuum thermal test is verified and realized. The problem of displacement measurement in domestic spacecraft thermal test is solved.

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