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Research and Calibration Experiment of Characteristic Parameters of High Temperature Resistance Strain Gauges

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Abstract: The difficulty of high-temperature strain measurement is that the sensitive coefficient, mechanical hysteresis and creep are not able to be compensated, which leads a big deviation. In order to solve the problem, a high-temperature strain calibration device, loading device and acquisition system are established, the experiment of parameters calibration of high-temperature strain gauges is carried out. The discipline of sensitive coefficient, mechanical hysteresis and creep changing with temperature of high-temperature is achieved. It is proved that the high-temperature strain gauges have a good performance at 800 °C and the manufacturing process, fixation, calibration system and experimental program are practicable. The calibration method provides the basis of similar experiments of strain gauges. *Copyright © 2013 IFSA.*

Keywords: Strain measurement; Characteristic parameters; Calibration; High temperature.

1. Introduction

The recent years have witnessed a steady rise in the use of high temperature strain measurement in aerospace, chemical, metallurgical industry and other sectors. The influence of the high temperature environment has always been a difficult problem for high temperature strain measurement. Targeted measures need to be taken to ensure the feasibility of the testing process and the accuracy of experimental data [1]. High temperature strain measurement methods are fringe method, speckle interferometry and electrical measuring method, but the most direct, the most widely used and most effective stress and strain measurement technique is contact high temperature strain measurement when considering the measurement accuracy, ease of use, and cost [2, 3].

The main difficulties of contact high temperature strain measurement is due to the high temperature creep and hysteresis of the strain gauge material, and the temperature compensation cannot be achieved effectively, which are together with strain gage thermal instabilities affect actual measurement results greatly [3].Strain gauges imported provide only room temperature sensitivity coefficient and resistance value, the remaining parameters are not available [4]. There has been an urgent need to establish a high temperature strain gauge calibration system and the corresponding calibration method, to calibrate the characteristics and parameters of high temperature strain gauges at different temperatures.

This paper established a high temperature strain calibration system, and did sufficient research in high temperature strain gauges' calibration of parameters, which laid the necessary theoretical and experimental basis for high temperature strain measurement technology. This paper presents a high temperature strain gauge parameter calibration method which has considerable promotional value.

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2. Introduction to Calibration Device of High Temperature Strain Gauges

The high temperature strain calibration device mainly consists of equal strain calibration beam and a loading device. The Calibration beam is simply supported in the furnace. The dimensions and loading method is illustrated in Fig. 1.

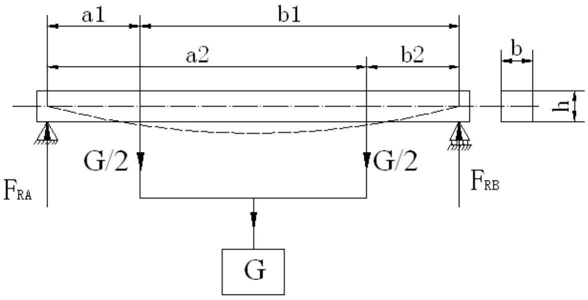

Fig. 1. Sketch of the calibration beam.

According to the loading mode of the calibration beam, the bending moment between the two load points of the beam is

$$M = F_{RA} \cdot x - \frac{G}{2}(x - a_1), \quad (1)$$

where $F_{RA} = \frac{G}{2}$.

So,

$$M = \frac{G}{2}a_1 \quad (2)$$

The bending moment diagram of the calibration beams is shown in Fig. 2.We can see that the bending moment between the loading points is equal, which enables us to install several strain gauges and calibrate it at the same time.

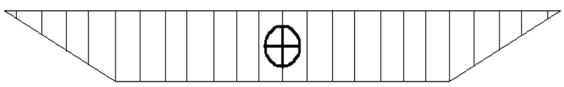

Fig. 2. Bending moment diagram of the simple supported beam.

The structural design of the calibration device refers to the national voluntary standards of resistance strain gauges GB/T13992—92.As is shown in Fig. 3. The specified weight is loaded to the calibration beam at room temperature. Specified deflection is loaded to the beam at high temperature calibration. During high temperature strain gauge calibration, we can control the strain between the loading points of the calibration beam directly through the deflection loading method, regardless of the material properties of the calibration beam. As is shown in equation (3)

$$\varepsilon_0 = \frac{12hf}{3l^2 - 4a_1^2} \quad (3)$$

where h is the thickness of the calibration beam, f is the deflection at the middle of the calibration beam, l is the valid length of the calibration beam; a_1: is the distance from the loading position to the supporting point of the same side.

Fig. 3. Picture of the furnace and the loading device.

At high temperature conditions, the elastic modulus and other parameters change with temperature particularly. Precise strain can't be got value if the weight loading method is used while by using the deflection loading method you can guarantee the strain value of the calibration beam and improve the accuracy of the calibration.

Fig. 4 shows the temperature control system. Along the longitudinal direction of the calibration beam in the furnace fixed three thermocouples which collect the left, middle and right part of the beam' temperature. By controlling the heating power we can control the furnace temperature, and by writing different programs we can control the heating, cooling and heat preservation process.

Fig. 4. Picture of the temperature control system.

3. High Temperature Strain Calibration Principle

The composition of high temperature strain measurement system is shown in Fig. 5. Fig. 6 shows the flowchart of the Signal acquisition which mainly consists of sensor (resistance strain gauges, thermocouples), signal conditioner (measuring bridge, strain amplifier), data acquisition card and computer. Thermocouple gets the real-time temperature of the measured point. The resistance strain gauge is linked to the electrical bridge. The strain is converted to a voltage signal transmitted to the strain amplifier for voltage amplification and filtering, etc. Data acquisition card sample, quantify and code the signals after conditioning which transforms the analog signal into a digital signal. The converted digital signal is conveyed into the computer through the interface, and then the computer analyzes the signal.

Fig. 5. Picture of the acquisition system.

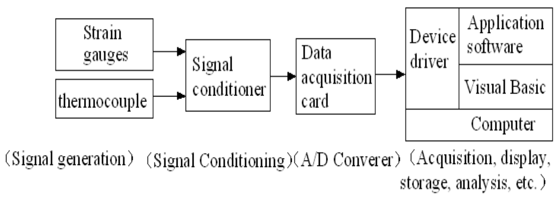

Fig. 6. Flowchart of the signal acquisition.

4. Parameters Calibration Experiment of the Strain Gages

4.1. Calibration of the Sensitivity Coefficient

Sensitivity coefficient determines the relationship between the strain and the output of the bridge which is one of the most important factors of the resistance strain gauge. In the test process, the sensitivity coefficient of the high temperature strain gauge changes with temperature [5, 6]. That is to say, we should calibrate the sensitivity coefficient of the high temperature strain gauge at different temperatures and compensate the test result for changes caused by temperature, Thus reducing the resulting error and ensuring the accuracy of the measurement [7].

During the calibration experiments, there is

$$K_0 \varepsilon_0 = K_{\mathrm{Y}} \varepsilon_{\mathrm{P}} \quad (4)$$

This means

$$K_0 = K_{\mathrm{Y}} \varepsilon_{\mathrm{P}} / \varepsilon_0 \quad (5)$$

where K_0 is the sensitivity coefficient of the strain gauge at room temperature;

ε_0 is the real strain of the calibration beam;

K_{Y} is the preset sensitivity coefficient of the dynamic strain meter (usually $K_{\mathrm{Y}}=2$);

ε_{P} is the indicate strain value of the strain meter during measurements.

The real strain value of the calibration beam is determined by equation (3). So we can obtain the sensitivity coefficient of the strain gauge by getting the readings of the dial indicator and the indicated strain value of the strain meter.

Gelatinize the strain gauge for three times, which process need go through a curing and a high temperature thermal cycle work, the strain gauge is fixed.

Add load to the calibration beam with reference to the national voluntary standards of resistance strain gauges GB/T13992-92. Record the readings of the dial indicator and the indicated strain of the acquisition system. The sensitivity coefficient of the strain gauge can be obtained by equation (5). Data of the acquisition system is shown in Fig. 7.

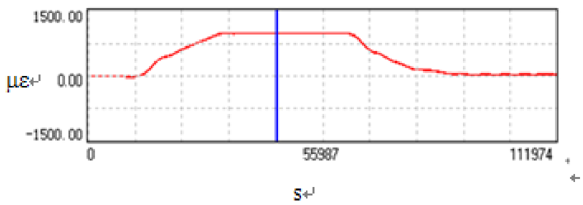

Fig. 7. Acquisition data of the room temperature sensitivity coefficient calibration.

Repeat the loading process for three times. The average room temperature sensitivity coefficient of the strain gauge is

$$\overline{K_0} = \sum_{i=1}^{n} K_{0i} / n = (2.226 + 2.243 + 2.286) / 3 = 2.252 \quad (6)$$

Similarly, we can get the sensitivity coefficient range from 200 °C to 800 °C, and get the sensitivity coefficient curve which varies with temperature by a fitting process.

The Fig. 8 shows the sensitivity coefficient's linear fitting curve calibrated at different temperatures. we can see the sensitivity coefficient of the high temperature strain gauge is decreased when the temperature increases. When the temperature reaches 800 °C, the sensitivity coefficient of the strain gauge is still 1.786. During the measurement, the thermocouple collects the temperature information of the beam's surface; the system changes the sensitivity coefficient with temperature which improves the accuracy of the measurement consequently. Since the calibration of the strain gauge's sensitivity coefficient is a destructive testing, it is impossible to calibrate all the strain gauges to determine the sensitivity coefficient of the strain gauges. So we select six strain gauges out of the same batch of products as a sample randomly. We use the sample to infer the overall mean and variance of the sensitivity coefficient, so as to define the strain gauge's accuracy class [8].

The room temperature sensitivity coefficient of the six strain gauges is listed in the following Table 1.

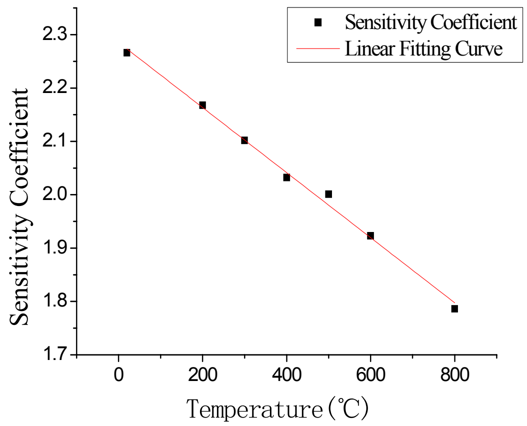

Fig. 8. Sensitivity coefficient at different temperature.

Table 1. Room temperature sensitivity coefficient.

Number of the strain gauges	Sensitivity coefficient
1	2.125
2	2.128
3	2.156
4	2.102
5	2.110
6	2.126

The average sensitivity coefficient of the six strain gages is

$$\overline{K}=\sum_{i=1}^{n}K_i/n=2.125 \tag{7}$$

The standard deviation of the sensitive coefficient at room temperature is

$$S=\sqrt{\sum_{i=1}^{n}(K_i-\overline{K})^2/n-1}=0.01857 \tag{8}$$

And

$$S=0.018566\leq\frac{0.02\overline{K}}{1.96}=0.02168 \tag{9}$$

According equation (8) and (9), by referring to the national professional standards of resistance strain gauges ZBY117-82, the high temperature strain gauge in the paper is belong to B-level resistance strain gauge [1, 9] .

4.2. Calibration of the Mechanical Hysteresis

The mechanical hysteresis is the difference between the output readings of the Strain gauges while the applied load is the same. One of the readings was gotten from the process begun by the minimum load, and the other one was gotten from the load reducing process. The amount of mechanical hysteresis can be reduced by repeated loading and unloading to the Specimen, generally for 3 to 5 times [10].

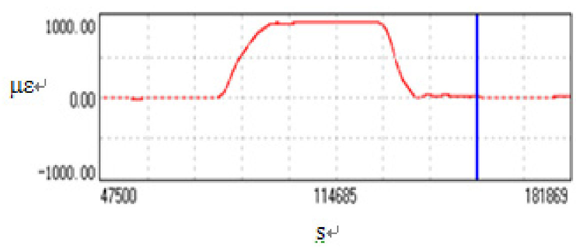

Fig. 9. Data collection in mechanical.

Mechanical hysteresis error can be gotten from the loading and unloading curves obtained. During the high temperature strain measurement, the presence of mechanical hysteresis brings error to the measurement result which needs to be calibrated.

The calibration procedure refers to the national voluntary standards of resistance strain gauges GB/T13992-92.The following Fig. 9 and Fig. 10 show the loading and unloading curve during the calibration of mechanical hysteresis at room temperature.

Similarly, we can get the mechanical hysteresis data from room temperature to 800 °C. The data and the linear fitting curve are shown in Fig. 11.

There is no doubt that temperature has a significant impact on the lags of strain gauges. The value of mechanical hysteresis will increase with the rising of temperature. The measurement results are required to be compensated for changes in temperature so as to improve the measurement accuracy.

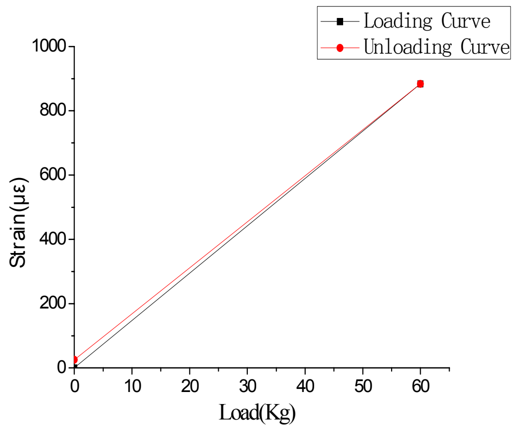

Fig. 10. Mechanical hysteresis curve at room temperature.

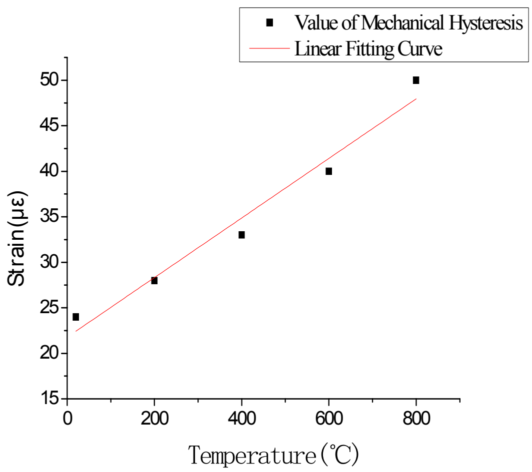

Fig. 11. The mechanical hysteresis data and the linear fitting curve.

4.3. Calibration of the Strain Gages Creep Parameters

At a certain high temperature, the strain gauges withstand a constant mechanical strain, while the resistance value changes with time. This is what called creep of the strain gauges [10]. Generally, we use these characteristics to measure the stability over time of the strain gauges. This is more prominent in long-term measurement.

The calibration procedure refers to the national voluntary standards of resistance strain gauges GB/T13992—92. Record the strain of the gauge every 10 minutes [11].

The Fig. 12 and Fig. 13 show the creep curves in 20 minutes at 200 ℃ and 800 ℃while the initial strain is 1000 με. It is obvious that the strain gauge's output increases with time. The creep values for 20 minutes were 32 με and 109 με each.

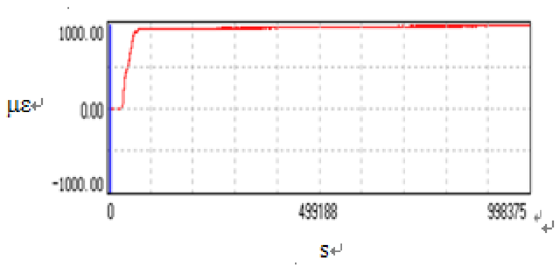

Fig. 12. Creep curve at 200 °C.

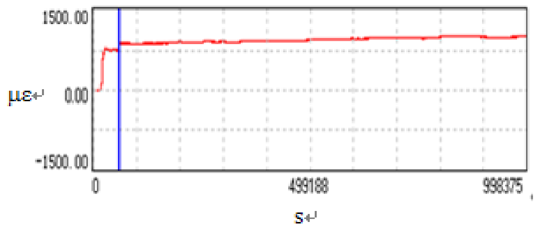

Fig. 13. Creep curve at 800 °C.

The creep value changes with temperature. The respectively measured creep values of the strain gauges are listed in the following Table 2.

Table 2. Creep value at different temperature.

Temperature (°C)	**Creep value (με)**						
	1	2	3	4	5	6	7
20	0	2	27	32	48	76	96
200	0	11	32	43	97	102	123
400	0	18	31	51	65	76	101
600	0	15	37	50	52	92	132
800	0	65	109	122	173	182	208

In the first 10 minutes, the output change of the strain gauge is very small. In one hour after loading the output change is about $100\mu\varepsilon$. When the temperature reaches 800 °C, the relaxation characteristics of the glue line becomes more apparent [12], the creep value of the strain gauge becomes significantly larger. Taking the analysis listed above, we can see that creep have a significant impact on measurement results. We can calibrate the creep value and establish creep compensation models, so as to improve the accuracy of high temperature strain measurement.

5. Conclusions

In the paper，high temperature strain gauge is fixed on the surface of a simple supported beam. The sensitivity coefficient, mechanical hysteresis and creep were calibrated from room temperature to 800 °C which suggests the good performance of the strain gage being used in this paper at 800 °C. The experimental results verify the validity of the manufacturing process, fixation methods, calibration system, and experimental feasibility. Last but not the least, this paper provides a basis for similar strain gauge experiments.

In this paper high temperature strain calibration system is established, which consists of temperature control system, loading device and acquisition system. Via the strain calibration system， the parameters of high temperature strain gauge calibration experiment method are put forward, whose changing rule in different temperature is get, which laid a foundation for the accuracy of high temperature strain measurement. Also，this research method in the paper can be applied to other resistance strain gauge parameters calibration.

Acknowledgement

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