Measurement of Thermal expansion coefficient of solid Materials by double slit Interferometric method

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Abstract. Thermal expansion coefficient is a regular coefficient to describe the variation of geometric characteristics of matter under the action of thermal expansion and cold shrinkage effect, and it is an important index to measure the thermal stability of materials. A device for measuring the thermal expansion coefficient of solid materials by Yang's double slit interferometric method with variable double slit spacing is mainly composed of laser, sliding Young double slit structure, temperature measuring and controlling instrument, shading tube, receiving device and solid material to be measured. The solid material is heated by ring heater, the temperature of solid material is displayed and controlled by temperature measuring and controlling instrument, and the change of stripe spacing is recorded by linear CCD image sensor. Compared with the traditional optical leverage method, this measuring device and method can significantly improve the accuracy of the measurement results and reduce the uncertainty of the measurement results.

1. Introduction
Thermal expansion means that the volume or length increase when the temperature rises. Thermal expansion coefficient is one of the main physical properties of materials. The accurate measurement of thermal expansion coefficient is of great significance in scientific research and technical application. Therefore, many universities and colleges have set up experiments to measure the thermal expansion coefficient of solid materials.

In the early 18th century, scientists began to study the thermal deformation law and thermal properties of materials. With the sustainable development of industrial modernization, the application demand and standards of solid materials are also rising, and the search for solid materials with good performance and good thermal stability has become the goal pursued by many precision instrument producers.

At present, the main methods used to measure the thermal expansion coefficient of materials at home and abroad are optical lever method, laser speckle interferometric method and Michelson interferometric method.

The thermal expansion coefficient of the metal rod is obtained by using the small change of the thermal extension of the metal rod, the angle of the reflection plane mirror and the reading difference of the ruler in the binoculars, and the thermal expansion coefficient of the material to be measured is obtained by comparing the shape variables of the target specimen with the standard specimen by using the optical method. Michelson interferometric method is to calculate the shape variable of the thermal expansion of the material by recording the variation of the interference ring by using the ring produced by optical interference, and then calculate the thermal expansion coefficient of the material.
These methods have their own advantages and disadvantages, for example, the experiment is time-consuming, the repeatability is poor, the experimental method is imperfect, so how to simplify the operation of the experiment and improve the experimental method is very important. As a kind of experimental device with reasonable design and convenient operation, the thermal expansion coefficient of solid materials measured by double slit interferometric method can avoid various disadvantages of traditional measurement methods, including tedious telescope adjustment, redundant data processing, difficult to control temperature regulation and so on.

2. **Experiment**

2.1. **Configuration and structure of double slit interference device**

The device for measuring thermal expansion coefficient of solid material by double slit interferometry is mainly composed of He-Ne laser, sliding Yang's double slit structure, ring heating tube, temperature measuring and controlling instrument, shading tube, USB linear array CCD receiving device and solid material to be tested. The experimental device mainly includes a laser with an observation device and a double-slit system between the laser and the observation device. The double-seam system comprises a shell structure and a double-seam device, a ring heating tube is arranged inside the shell, the metal rod to be tested is closely combined with the ring heating tube, a temperature sensor in contact with the metal rod to be tested is arranged inside the shell, and the temperature sensor is connected with the temperature measuring instrument through a wire to read out and control the temperature in real time. The double slit interferometry device for measuring the thermal expansion coefficient of solid materials is shown in Fig.1.

![Figure 1. A device for measuring Thermal expansion coefficient of solid Materials by double slit Interferometric method.](image)

2.2. **Experimental principle**

By using the phenomenon that light interferes through double slit to produce light and dark fringes, it is possible to measure the small change of material shape under different temperature conditions. A new device for measuring thermal expansion coefficient of materials by using double slit interference principle is designed. USB linear CCD data acquisition system is used to measure the stripes spacing in real time, which effectively reduces the influence of human factors in the experimental process. The rapid and automatic measurement of thermal expansion coefficient of materials is realized.

2.2.1. **Experimental flow analysis.** The laser emits a beam and interferes through the Yang's double slit structure with variable spacing. The order seam of the variable spacing Yang's double seam structure is connected with the solid material to be tested (the vertical length of the solid material to be tested is L, the diameter is d) through the insulated connection mechanism, and the upper single seam is connected to the shell through the bracket. The power supply of the heating cylinder gives the solid material to be tested a continuous heat supply, and the solid material to be tested expands by heat, and
then produces a small shape variable $\Delta L$ in the vertical direction. The solid material to be tested drives the thermal insulation connection mechanism at the top of the solid material and the sending order seam fixed connection with the insulation connection mechanism to move upward, and the above movement will eventually lead to the shortening of the distance between the upper and lower single seams, At this time, the change of the distance between the upper and lower single seams, that is, the distance between the two seams, is $\Delta b$. During this period, the temperature indicator shows the number of temperature before and after expansion. The decrease of the distance between the upper single slit and the lower single slit will lead to the increase of the centre distance of the interference fringes.

The USB linear CCD receiver captures the optical signal, selects the striped series m, n on the same side, records the temperature $T_1$ and stripe spacing $\Delta X_{1mn}$ at this time, the selected temperature gradient is $T_2$, the recording temperature $T_2$ and stripe spacing $\Delta X_{2mn}$, the distance between the double slit device and the USB linear CCD receiver is $D$, and then the thermal expansion coefficient of the specified solid material can be calculated according to the corresponding fixed light wave wavelength on the laser.

![Experimental schematic diagram.](image)

**Figure 2.** Experimental schematic diagram.

### 2.2.2. Interference fringes analysis

Double-slit interference fringe refers to the fringe in the central maximum contour of single-slit diffraction, and the interference fringes in the secondary large profile of diffraction on both sides are generally not discussed because of their weak light intensity. During the experiment, the width of single seam was kept unchanged. The distance between the two seams was changed. Since the width of the slit remains unchanged, the width of the maximum of the diffraction centre of the single slit is almost unaffected. With the reduction of the gap between the two cracks, the interference fringes "appear" outward in a "dense formation".

When interference occurs in light passing through a double slit:

$$I = I_1 + I_2 + 2\sqrt{I_1 \cdot I_2} \cos \Delta \varphi$$  \hspace{1cm} (1)

When $I_1 = I_2$,

$$I = 4I_1 \cos^2 \frac{\Delta \varphi}{2}$$  \hspace{1cm} (2)

When light interferes, the position of the light and dark stripes,

$$x = \pm \frac{kD\lambda}{d} \quad (k = 0, 1, 2 \ldots)$$  \hspace{1cm} Clear grain center

$$x = \pm (2k - 1) \frac{D\lambda}{d} \quad (k = 1, 2, 3 \ldots)$$  \hspace{1cm} Dark grain center

$k = 0$ in the center of the screen is the central bright stripe (where k is called the series of stripes).
3. Thermal expansion coefficient conversion measurement

3.1. Introduction of thermal expansion coefficient

The thermal expansion coefficient is the length change of the appearance of the corresponding sample under the condition of temperature change, expressed by \( \Delta L/L_0 \) (\( \Delta L \) is the measured length change, \( L_0 \) is the material length under the reference temperature \( t_0 \)). If the lengths of the material at \( T_1 \) °C and \( T_2 \) °C are \( L \) and \( L_1 \), respectively, the corresponding thermal expansion coefficient in the temperature range is:

\[
\alpha = \frac{L_1 - L}{L(T_2 - T_1)} = \frac{\Delta L}{L(T_2 - T_1)}
\]  

(5)

Where \( \alpha \) is the thermal expansion coefficient of the material.

3.2. Formula conversion of optical micro variables

Turn on the switch and heat the measured solid material. After the solid material is heated and expanded, the length change of the solid material is \( \Delta L \), and the reduction of the distance between the two seams is \( \Delta b \). Of which,

\[
\Delta b = \left( \frac{D\lambda}{\Delta x_{1mn}} - \frac{D\lambda}{\Delta x_{2mn}} \right)
\]  

(6)

\( \Delta b = \Delta L \) (\( \Delta b \) is the reduction of double slit spacing and \( \Delta L \) is the expansion of solid material).

\[
\alpha = \frac{\Delta b}{L(T_2 - T_1)}
\]  

(7)

The wavelength of the laser produced by the laser is \( \lambda \), and the above \( \Delta b \), \( \Delta L \), \( L \), \( D \), \( T_1 \), \( T_2 \), \( m \), \( n \), \( \lambda \) and \( \Delta X_{1mn} \), \( \Delta X_{2mn} \) are substituted into the formula to obtain the formula.

\[
\alpha = \frac{D\lambda}{L(T_2 - T_1)} \left( \frac{1}{\Delta X_{1mn}} - \frac{1}{\Delta X_{2mn}} \right)
\]  

(8)

By replacing the above measured values with the above formula, the thermal expansion coefficient of the metal rod to be measured can be obtained by calculation.

4. Measurement

The method follows the following steps:

A, firstly, the metal rod to be tested is placed in the heating tube of the shell, and the top of the metal rod to be tested is connected with the order slot in the double-slit device through the insulated connection mechanism.

B, the He-Ne laser is started, the beam emitted from the laser passes through the double-slit device, enters the shading tube, and finally produces the interference phenomenon of light and dark stripes on the receiving screen of the optical signal.
C, control the resistance wire to turn on electricity, heat the measuring metal rod and make it expand, so that the distance between the upper single slit and the lower single slit is reduced, and the temperature controller can be adjusted to observe and control the temperature in real time. The stripe series m, n on the same side is selected to record the corresponding temperature and stripe spacing.

D, the experimental data are recorded, several sets of experimental values are measured, and the average value and uncertainty are obtained.

5. Conclusion
In this paper, a new device with simple structure and ingenious design is presented for thermal expansion coefficient of solid materials. In view of the problems existing in the traditional measurement method of thermal expansion coefficient, a micro variable transformation method is designed according to the fact that the expansion of solid materials is equal to the reduction of double slit spacing and that the reduction of double slit spacing corresponds to the increase of the center spacing of adjacent interference lines. According to the principle of Yang's double-slit interference experiment, the Yang's double-slit structure with variable double-slit spacing is made, and the double-slit structure can be sliding connected to reduce the error source in the experimental process; The black shading tube makes the dark environment for interfering the optical path to avoid the interference of external light. In addition, the modification of the device can also measure the young's modulus of the filament, which is widely used, suitable for popularizing in this field.

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