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STUDY ON INFRARED RADIATION TEMPERATURE MEASUREMENT WITH OPTICAL FIBER SENSOR

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Abstract: The temperature in dangerous warehouse where deposit is flammable or explosive is difficult to be measured. This paper analysis the theory of infrared radiation measurement at low temperature, and presents a new type of measurement system. In this system, the radiation energy of deposit is focused on the optical fiber sensor. The equipment of the infrared focus and the structure of the optical fiber sensor are discussed.
Keywords: infrared radiation measurement, temperature measurement, optical fiber sensor

1 INTRODUCTION

If the deposit piled in a danger warehouse is flammable or explosive, the conventional methods on the temperature measurement can not meet the demand of deflagrating precaution. With the development of the optical fiber temperature sensor, we find a new way to measure the temperature in the danger warehouse.

2 MEASUREMENT THEORY

2.1 radiation field energy transition

The interior of the danger warehouse can be regarded as a radiation field, the radiation flux of the deposit is changed with its surface temperature.

If the surface temperature of the deposit is T, the area of the radiation field is A, the radiation flux is f ,we get:

$$f = e \cdot s \cdot T^4 A$$

(1)

In equation (1), e is steradiancy, $s = 5.67\times 10^8 (W \cdot m^{-2} \cdot K^{-4})$

A part of radiation energy arrives at the spherical surface, and is focused on the temperature sensor. If the radiation steric angle is Ω ,the reflectivity of spherical surface is r ,the photospot degree of spherical surface is x .then the energy on the sensor is:

$$f_1 = r \cdot e \cdot \Omega \cdot s \cdot T^4 Ax \qquad (2)$$

The energy is focused on the optical fiber sensor, and offers caloric to the sensor. If the quantity of heat is Q_1 , the temperature of sensor rises from t_1 to t_2 , then the optical fiber sensor attains to local caloric-balance. If the quantity of the sensors convection heat is Q_c ,the conduction heat is Q_t ,and radiation heat is Q_r , according to law of conservation of energy,we get

$$Q_1 = Q_c + Q_t + Q_r$$

(3)

Because the thermal conductivity of the optical fiber is small ,and the constant cross-sectional area is small too, the Q_t approximates zero, then

$$Q_1 = Q_c + Q_r$$

(4)

The quantity of the sensors convection heat Q_c is:

$$Q_c = m \cdot C_p \cdot (t_2 - t_1)$$

(5)

where, m is the mass of the sensor, C_p is specific heat of the sensor, t_2 is the temperature of the sensor, t_1 is the temperature of the environment.

If the steradiancy of the sensor is e_1, the area of the surface of the sensor is A_1, the sensor's radiation flux is f_r, and the quantity of the sensor's radiation heat is Q_r :

$$f_r = e_1 \cdot s \cdot A_1 \cdot t_2{}^4 \quad (6)$$

$$Q_r = J \cdot e_1 \cdot s \cdot A_1 \cdot t_2{}^4$$

(7)

In equation (7), J is the mechanical equivalent of heat .

From equation (2),(5),(7)and (4),we get:

$$J \cdot e \cdot s \cdot T^4 \cdot \Omega \cdot r \cdot x \cdot A_1 = m \cdot C_p \cdot (t_2 - t_1) + J \cdot e_1 \cdot s \cdot t_2{}^4 A_2$$

(8)

It follows that the temperatuer of optical fiber relates to the surface temperature of the deposit.

2.2 The thoery of the optical fiber temperature sensor

The light spreading in the optical fiber is modulated by temperature, the intention ratio of the backscatted Stokes-Raman light and Antistokes-raman light in the sensor relates to the temperature of optical fiber:

$$R(t_2) = \left(\frac{l_s}{l_a}\right)^4 e^{\left(-\frac{hc\,u}{Kt_2}\right)}$$

(9)

then:

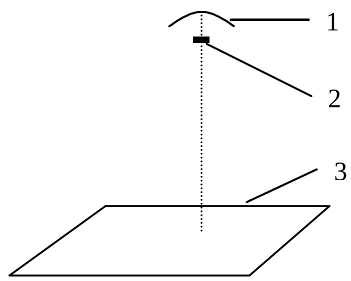
$$t_2 = \frac{hc\,u}{K\left(4\ln\left(\frac{l_s}{l_a}\right) - \ln R(t_2)\right)}$$

(10)

where, l_s is the wavelength of the backscttered Stokes-Raman light, l_a is the wavelength of the backscattered Anti-stokes-Raman light is Planck constant is the velocity of light is Boltzmann constant t_2 is the temperature of the sensor u is the frequency of the incident light.

Therefore, a measurement of the ratio of the backscattered Stokes-Raman light and Anti-Stokes-raman light in the fiber should provide an absolute indication of the temperature of the medium,irrespective of the light intensity, the launch conditions, the fiber geometry and even the composition of the fiber.

3 MEASUREMENT SYSTEM



1.spherical surface 2.optical fiber sensor
3. surface of radiation deposit

fig 1: measurement system

The temperature measurement system of the danger warehouse is shown in fig 1.

The deposit surface radiates infrared ray that relates to the temperature of itself, the wavelength is about 10 m. A part of radiation-flux is focused on the optical fiber sensor by the sphere mirror. The temperature of the optical fiber relates to the temperature of deposit surface.

In the optical fiber, the scattered light is modulated by the optical fiber temperature, and transmitted to the detector outside of the warehouse, and processed by the computer.

In order to increase the reflectivity for infrared ray of the spherical mirror, we overlay aluminum on the surface of the spherical mirror.

4 SPHERICAL MIRROR DESIGN

An optical focusing system is needed for the radiation energy arriving to the optical fiber sensor. An reflective spherical surfaces can do it. The radiation rays can be focused at a little area around the focal point in the focal plane via the reflective spherical surfaces. The optical fiber sensor can be arranged at the focal point to measure its temperature. As the temperature of the radiation field approximates the room temperature, the radiation field can radiate infrared way**.** The wavelength of the radiation ray is about 10um. In order to increase the reflectivity of the spherical surface, we overlay aluminum on the surface of the spherical mirror.

According to the geometry optical law , the spherical surface used to focused the radiation rays can be designed. How to design the spherical surface is shown in Fig 2.

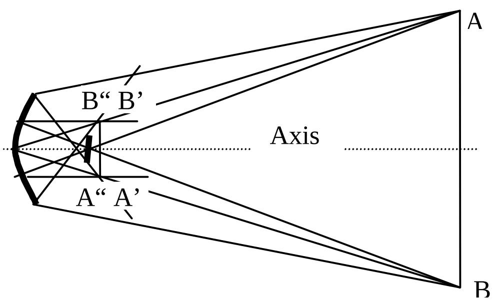


Fig 2 spherical surface design

1) Those incident rays through the focal point are reflected into parallel rays.

2) Those incident rays through the spherical surface top point are reflected . The incident angle equals to the reflection angle.

3) The point of intersection of the two rays is the point of image. The height of the image is A’B’

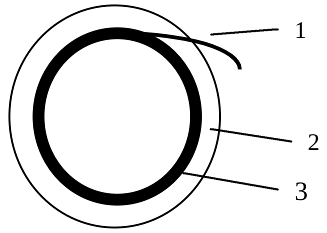
4) Those incident ways through the fringe of the spherical surface are reflected through the image point.

5) The vertical line of the light axis through the focal point intersects with the reflection rays of the margin incident rays. The area of the intersection is focal spot. The diameter of the focal spot is : d=A“B“.

According to the image law and geometry equation, the parameter of the ideal spherical surface can be calculated.

Assume : the diameter of the radiation field is 6m the height of the warehouse is 4~5m, the height of the deposit is about 1~2m then the parameter of the spherical surface is :
Focus f =0.15m, curvature radius r =0.30m, caliber l=0.50m,
The height of the coronal h =0.1325m, diameter of the focus spot d=0.05m,

5 OPTICAL FIBER SENSOR [1][2]



1 optical fiber for transmitting
2. copperplate 3.optical fiber ring
Fig 3 the optical fiber sensor

The optical fiber sensor is put on the focal point of the spherical surface mirror. The structure of the optical fiber sensor is shown in Fig.3. The sensor includes three sections: the optical fiber rings is the main body of the sensor, the temperature is sensed via it ; the light signal must be transmitted through the optical fiber; the copperplate is the bracket of the optical fiber rings, Because the diameter of the focus spot is 0.05m, the diameter of the copperplate is 0.05m, the thickness of the copperplate is 0.2mm .The optical fiber for sensing is about 10m long, it is rolled as optical fiber rings, the diameter of the rings is 0.04m. The optical fiber rings is attached on the copperplate, and is nigrified.

5 SYSTEM STRUCTURE

A pulsed semiconductor laser is coupled into a section of the fiber via a directional coupler, which serves also to couple the backscattered light fraction, the backscattered light is disparted into anti-Stokes-Raman scattering and Stokes-Raman scattering via the wavelength-division multiplexer (WDF), the Stokes-Raman light and anti-Stokes-Raman light are captured by the avalanche photodiode (APD) detector, amplified by the amplifier ,sampled by the high speed sample card, and processed by the computer. According to the principle ,the intention ratio of backscattered Stokes-Raman light and anti-Stokes-Raman light in the fiber should provide an absolute indication of the temperature of the radiation field. The measurement system structure is shown in Fig.4 Only the optical fiber is put inside the warehouse, the others of the system is put outside the danger warehouse.The optical fiber is used as both a temperature sensor and a light transmiter .This is a safe measurement way for the warehouse.

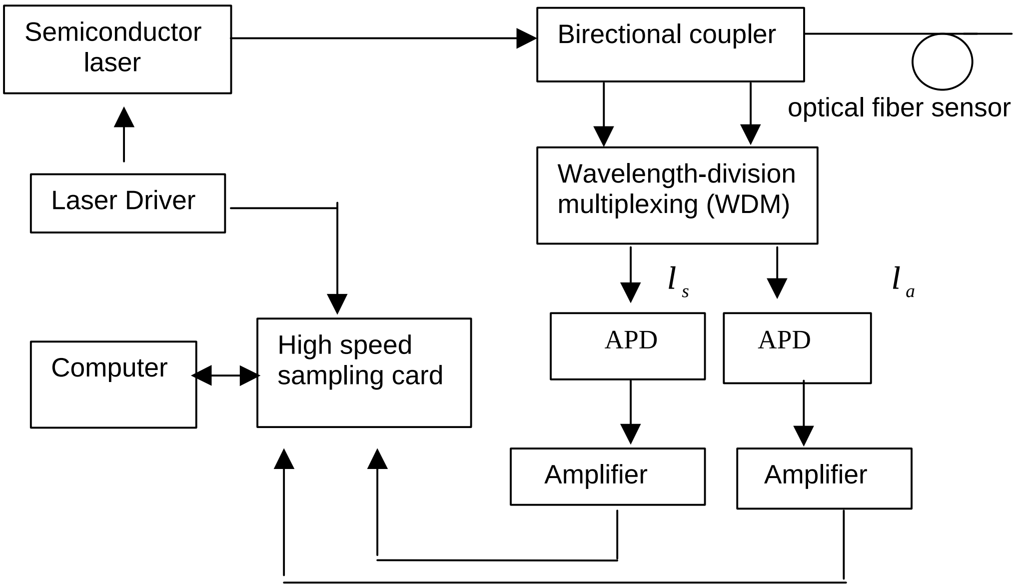


Fig 4 optic fiber measurement system structure

A pulsed semiconductor laser is coupled into a section of fiber via a directional coupler, which serves also to couple the backscattered light fraction, disparted into anti-Stokes-Raman scattering and Stokes-Raman scattering via the wavelength-division multiplexer , captured and returned via the fiber under test ,to the avalanche photodiode (APD) detector, amplified via the amplifier ,sampled via the high speed sample card, and processed by the computer. According to the principle ,the ratio of Stokes and anti-Stokes backscattered light in the fiber should provide an absolute indication of the temperature of the radiation field. The measurement system structure is shown in Fig.3. Only the optical fiber keeps inside the warehouse, the others of the system is outside the danger warehouse.The optican fiber is used as a temperature sensor, and light transmiser .This is safety for the warehouse.

6 EXPERIMENT

Using this system ,we get some experiment data , that is shown in table 1.

Table 1 . Experiment data

Temperature of the radiation field ^oC	Distance between the radiation field and the optical fiber sensor. m	Optical fiber sensor temperature ^oC
22	2	26.3
23	2	28.5
24	2	31.1
25	2	33.3
26	2	34.9
22	3	24.1
23	3	25.1
24	3	26.5
25	3	27.3
26	3	28.6
22	4	22.1
23	4	22.4
24	4	22.8
25	4	23.4
26	4	24.1

It is obvious that the measurement temperature is changed with the radiation temperature. When the radiation temperature hold the line, the distance between the optical fiber sensors and the radiation field is changed, the measurement temperature is changed too. This experiment testify the theory.

7 CONCLUSION

This is a new way to measure the temperature of danger warehouse. But its response speed is slow, and it needs to be developed.

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