THE NEW FIBER-OPTIC TEMPERATURE SENSOR FOR GREENHOUSE

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Abstract: In this paper, we introduced a new fiber-optic temperature sensor with white light interferometric principle based on Fabry-Perot, which is capable of providing measurement for the temperature of greenhouse. The signal processing of system is that the optical signal wavelength is modulated in the Fabry-Perot cavity and is demodulated during the optical-electricity transform. Compared with a common optical fiber strain sensor, it has more advantages, such as low cost, high stability, and high anti-interference. The resolution of the fiber optical temperature sensor is up to 0.01℃ within the test range being -40℃～100℃.The fiber-optic temperature sensor system made up of this fiber-optic temperature sensor is put into use in agriculture fields for monitoring in real time and absolute temperature measurement.

Keywords: optic fiber, temperature, interferometric, Fabry-Perot, greenhouse

1. INTRODUCTION

Along with national economic quick growth, the agricultural research and the application technology take more and more recognition, especially the hothouse has become the important part of the high-efficiency agriculture. It may not only provide the off-season fresh agricultural products, but also can create good economic efficiency. The growth vigor, quality and output of the crops in the hothouse are closely related with the temperature, humidity and soil moisture of the hothouse. Therefore the temperature measurement to the hothouse is a very important link. The traditional temperature measurement usually adopts temperature elements, thermocouples, thermistor as well as integrated temperature sensor and so on. But this kind of elements is easy to be limited by the fields measured by fields measured and the environment. And they should be examined and replaced regularly for the capability can be declined while high temperature or long-term use. Therefore the practical application is greatly inconvenient. Optical Fiber Temperature Sensor can be used in every kind of condition and environment (P.M Nellen, 1999, V.K.Varadan, 1999, Yang YH, 2007). In this paper, we introduced a new fiber-optic temperature sensor with white light interferometric principle based on Fabry-Perot, which is capable of providing measurement for the environment temperature. White light interferometry is a low coherent interferometer that is used to avoid error and noise caused by bending of the fiber and fluctuation of the light source (S.Vered, 2002). Compared with a common optical fiber temperature sensor, it has more advantage, such as low cost, high stability and absolute measurement.

2. SENSOR CONFIGURATION

The proposed temperature sensor structure is shown in Fig.1, the fiber sensor system is based on white-light interferometric principle, which signal processing is that the optical signal wavelength is modulated in the Fabry-Perot cavity with fiber sensor system, and is demodulated during the optical-electricity transform. For the sensor system, the Light emitting diodes (LED) is used as a white-light source, and the detector system is mainly made up of CCD photoelectric transform circuit. The designed fiber sensor is of fine linearity strain characteristic, highly precision and highly sensibility.

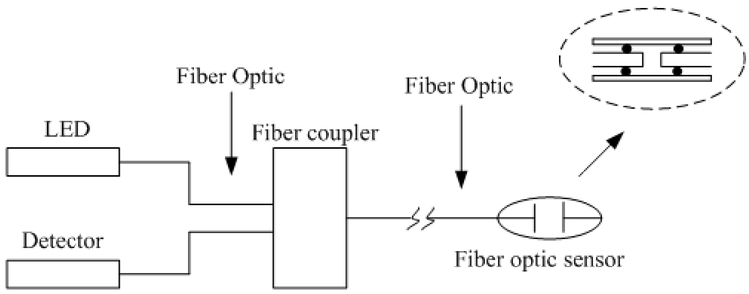

Fig.1. The fiber temperature sensor system

The optical fiber temperature sensor designed in this paper, is that the measured temperature is transformed into optical fiber Fabry-Perot the interference cavity length *L* change. Fig.2 shows the structure of fiber temperature sensor; the reflective fiber (RF) and the incident fiber (IF) are both infixed the hollow fiber which inner diameter (D_{in}) is micron magnitude and are cemented at the hollow fiber ending. M_1 and M_2 are the coating end faces for avoiding the loss. The distance between two fixed points is named gauge length (L_g), which influences the measurement range and accuracy of fiber strain sensor.

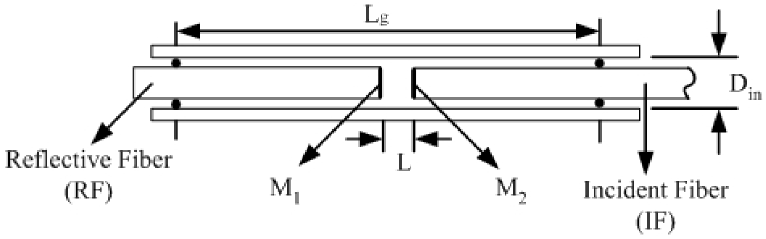

Fig.2. The fiber temperature sensor structure

The external strain changes modified the length of Fabry-Perot cavity, so the strain change $\Delta\varepsilon$ is proportional to the change of the length of Fabry-Perot cavity ΔL in the following way:

$$\Delta\varepsilon = \frac{\Delta L}{L_g} \quad (1)$$

According to stress-strain and temperature relations, in Cartesian coordinate, the component of strain caused temperature is:

$$\varepsilon_{xx} = \varepsilon_{yy} = \varepsilon_{zz} = kT \quad (2)$$

$$\varepsilon_{xy} = \varepsilon_{yz} = \varepsilon_{zx} = 0 \quad (3)$$

In the formula, k is object thermal-expansion coefficient; ε_{ij} (i, j=x, y, z) is measured body's in i, j direction component of strain. If only considers the optical fiber temperature sensor's axial strain $\varepsilon_{zz} = \Delta L / L_g$, the result in by the formula (2):

$$\Delta L / L_g = kT \quad (4)$$

When the reflective coefficient of surface $R << 1$, the multi-beam interference in Fabry-Perot cavity can be approximately considered as two-beam interference, the reflective light intensity I_R is (Bi Weihong, 1999):

$$I_R = 2I_0 R(1 + con\phi) \quad (5)$$

Where I_0 is the incident intensity, ϕ is the phase difference of two beams. Eq. (5) shows that the extreme point of reflective intensity appears with the follow equation meeting,

$$\phi = 2k\pi \qquad (k = 1,2,3\cdots) \quad (6)$$

The phase difference ϕ can be expressed:

$$\phi = \frac{4\pi}{\lambda} L \tag{7}$$

Where λ is the optical wavelength, L is the length of Fabry-Perot cavity. So the length of Fabry-Perot cavity can be showed:

$$L = \frac{\phi}{4\pi}\lambda = \frac{2k\pi}{4\pi}\lambda = \frac{k}{2}\lambda \qquad (k = 1,2,3\cdots) \tag{8}$$

Eq. (8) shows that the reflective intensity maximizing when the length of Fabry-Perot cavity is integer multiple of the optical half-wavelength. We design the optical strain sensor based on white light interference, which a short coherence length white source is used, and the white light source is LED that produces broadband emissions. In a Fabry-Perot light interferometer, the incident polychromatic wavelength is $\lambda_1, \lambda_2, \cdots \lambda_n$, so Eq. (8) can be written as:

$$L = \frac{k}{2}\lambda_i \qquad (i = 1,2,3\cdots n) \tag{9}$$

Then projected onto a CCD camera, the fringes can be captured and analyzed on an accompanying microcomputer. The advantages of the system include the absolute measurement capability and the potential for multiprocessing.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Because the temperature is decided to the optical fiber sensor's influence by the optical fiber temperature sensor carrier nature, the carrier volume, the carrier and between the optical fiber temperature sensor's cementation and uses the rubber with the rubber thickness. Regarding metals and so on carrier like copper, iron along with the temperature change are linear, simultaneously when the seal is not too thick with the rubber, optical fiber's volume to be opposite is very small in the carrier, the temperature and the strain relations are approximate are decided by the carrier temperature characteristic. The optical fiber temperature sensor mentioned in this paper, is housed in the diameter is in the 2.4mm copper pipe by rubber, which the thermal-expansion coefficient of copper is k=14.8×10-6/℃。

We analyze the experiments of temperature characteristic of fiber temperature sensor, and we measured the temperature characteristic of designed fiber strain sensor and the results presented in Fig.3, which black block expression for actual survey data, straight line expression fitting curve.

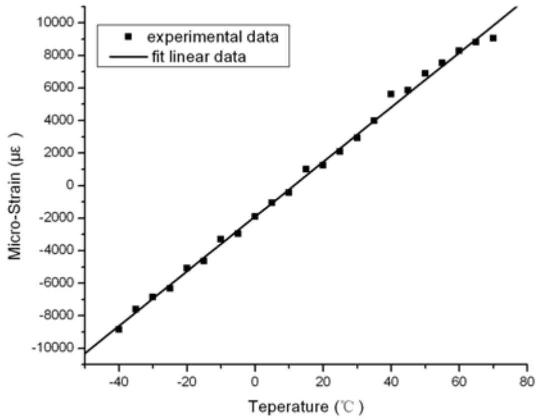

Fig.3. The temperature characteristic of fiber strain sensor

The results of temperature characteristic showed in Fig.3 were measured by the attemperator from –40℃to 70℃, the resolution achieves 0.01℃ and they presented goodness linearity strain characteristic, which linear fitting is 0.9943. But when the external environment temperature surpasses 90℃, the empirical datum and the theory fitting have the deviation, the reason possibly is that the temperature hysteresis quality of rubber influence measurement result which appears under the high temperature, causes the optical fiber temperature sensor's temperature change and the metal carrier temperature change is inconsistent.

Theoretically, the designed optical fiber temperature sensor unit cavity long change value is: $\Delta L / L_g \Delta T = 14.8 \times 10^{-6} / °C$; But the cavity long change value which obtains by the empirical datum is: $\Delta L / L_g \Delta T = 15.06 \times 10^{-6} / °C$. Because the experiment error in reading and the seal create with the rubber to the optical fiber temperature sensor's influence, the theoretical value and the experimental results are not completely same. This kind of error may carry on the compensation through the algorithm.

4. CONCLUSION

A new fiber-optic temperature sensor with white light interferometric principle based on Fabry-Perot was presented and investigated theoretically and experimentally, which the resolution achieves 0.01℃ from –40℃to 70℃ and it adopt to use in the greenhouse big awning the temperature survey, specially to temperature request high crops greenhouse big awning.

Compared with a common optical fiber strain sensor, it has more advantages, such as low cost, high stability, high anti-interference and absolute measurement. So it will certainly to have the widespread application prospect, further consummates its production process, definitely may achieve practical the request.

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