Study on Fiber Bragg Grating Displacement Sensing

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ABSTRACT

The paper proposes a novel demodulation method of fiber grating displacement sensing with applying dual grating structure. The linear tuning sensitive structure of isosceles triangle-shaped cantilever beam is designed which can be used to eliminate the influence from environmental temperature. The fiber grating is pasted in the cantilever top and under both sides. When the cantilever free end take place the displacement, this would generate strain which can make the gratings compression and tensile respectively, furthermore, cause the changes of Bragg grating reflection wavelength. The changes of grating is caused by temperature influence in the same direction, and caused by stress change in the opposite direction. Therefore, the change of optical power caused by temperature was offset, that is, eliminate the influence from environmental temperature. When the free end has displacement or load, the grating on beam top surface was stretched, Bragg wavelength drift to the long-wave direction, and the grating under the surface is compressed, which make wavelength drift to the short-wave direction. The changes of light intensity can be seen from the spectrogram. Using linear tuning properties without chirped of cantilever beam, micro-displacement in the free end can effective turned into the strain of equal intensity beam. The changes of Bragg wavelength caused by strain can be shown in optical power meter**,** and would be transformed into voltage display through demodulation system. Therefore, displacement sensing information is derived indirect; the optical measurement of micro-displacement is realized. The experiment result shows the system sensitivity is 0.87mV/μm, and displacement resolution is 2.12nm/mm.

Keywords: fiber Bragg grating (FBG), linear cantilever tuning, strain sensing, displacement sensing

1. INTRODUCTION

Fiber Bragg Grating (FBG) is a new kind of optical passive component which has the good sensitivity to the strain. Comparing with the traditional strain sensor (resistance strain silk, piezoelectric ceramics strain gauge), fiber grating has several distinguished advantages such as sensing information wavelength code , free from electromagnetic interference and can realize absolute measurement. It can be widely applied in the strain, temperature, pressure, magnetic and other detected fields[1-5]. How to detect the wavelength displacement of sensing grating are the key problems faced by its practical application. This article introduces a novel fiber grating displacement sensing demodulation system by applying dual grating structure, with high-resolution, demodulation fast, simple structure and so on.

2. THE DESIGN OF TUNING STRUCTURE

Essentially, the measurement of fiber grating sensing is the Bragg central wavelength shift $\Delta\lambda$ measurement. The sensing information must be enlarged because the wavelength shift is generally very small, tuning structure as shown in Figure 1.

Fiber Bragg gratings are pasted on the top and bottom surface of equal intension cantilever beam separately. When the beam free end happened displacement (or load P), the beam would generate a stain role in the grating axial, which would caused by the changes of Bragg reflection wavelength. When the temperature is invariable, the relative drift $\Delta\lambda/\lambda_B$ is directly proportional to the axial strain ε[6].That is:

$$\frac{\Delta\lambda}{\lambda_B} = (1 - P_e)\varepsilon \tag{1}$$

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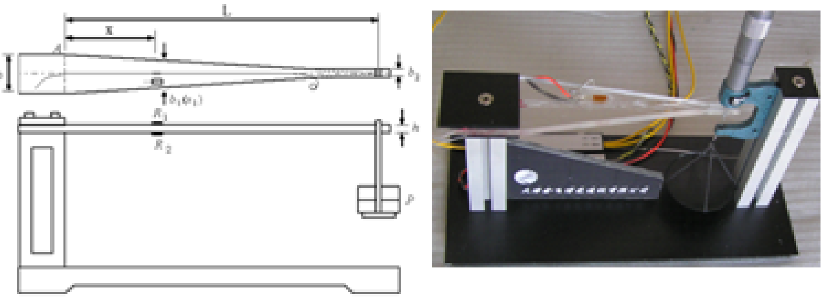

Fig.1 linear cantilever tuning structure

According to material mechanics, the strain ε_x along the x-axis direction on the cantilever beam can be expressed as [7-8]:

$$\varepsilon_x = \frac{\sigma_x}{E} = \frac{M_X}{E \cdot I_X} \cdot \frac{h}{2}. \tag{2}$$

Where σ_x is x stress, E is Yang-style module, M_x is the point of bending moment, Ix: the point where the cross-section moment of inertia about Y-axis

$$M_x = (L - x)P. \tag{3}$$

$$I_x = 1/12\, b_x h^3 \tag{4}$$

And L is arm length, P is the role of load, b_x is a cross-section width. Assuming the bending deflection of beam free end is small, excluding beam self-weight, because of variable cross-section beams, the relationship between the free end displacement and the load P is:

$$f = \frac{PL^3}{2EI} \tag{5}$$

It can be deduced the relationship between the wavelength change $\Delta\lambda_B$ and the free end displacement f and load P respectively.

$$\Delta\lambda_B = \frac{h\lambda_B(1-P_e)}{L^2} f \tag{6}$$

$$\Delta\lambda_B = \frac{6L\lambda_B(1-P_e)}{Eb_0h^2} P. \tag{7}$$

We can see that the axial strain ε_{ax} and Bragg wavelength changes $\Delta\lambda_B$ become the linear relationship with beam free end displacement f and load P. Therefore, micro-displacement f and load P can be obtained indirectly through measuring changes of Bragg wavelength caused by beam strain.

3. GRATING DEMODULATION PRINCIPLE

The grating sensing device as shown in Figure 2, there is a positive strain when FBGb is pasted on the beam surface, FBGa under the beam surface is a negative strain. The movement direction of their reflection wavelength is opposite. Optical signal by the FBGb reflected arrives at FBGa with the coupler, and the output signal FBGa transmission. Therefore, the Bragg wavelength changes caused by strain can be shown in optical power meter through the system optical power change.

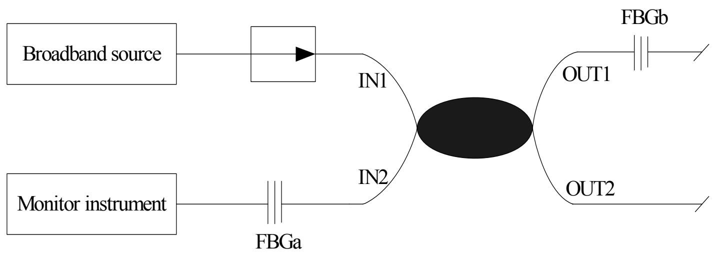

Fig.2. fiber grating sensing and demodulation system

Figure 3 (a) is fiber grating reflection spectrum, using dual grating to demodulation in the experiment. When there is displacement or load in the beam free end, the above grating is stretched, Bragg wavelength drifting to the long-wave direction, the following grating is compression, short-wave wavelength to drift, and it will form a Figure b-c-d situation. Central hollow is the compressed grating transmission peak, so the light intensity has the change. Fiber Bragg grating reflection spectrum linear can be approximated for the Gaussian distribution expression

$$R_i(\lambda) = R_i \exp[-4\ln 2 \frac{(\lambda - \lambda_i)^2}{\Delta\lambda_i{}^2}] \tag{8}$$

Where R_i is the grating peak value reflectivity, λ_i is center wavelength, $\Delta\lambda_i$ is half-intensity bandwidth.

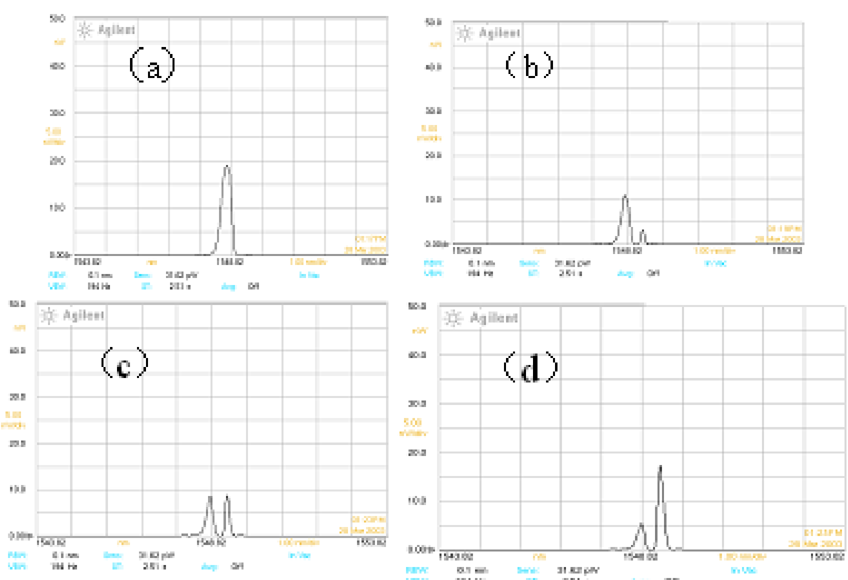

Fig.3. fiber grating demodulation spectrum

Broadband source bandwidth is much larger than the bandwidth of fiber Bragg grating, in fiber Bragg grating spectral width, the light source incident light can be regarded as constant. Therefore, the reflection intensity of sensing grating FBGb can be expressed as $I_0 R_{FBGb}(\lambda)$, where I_0 is the incident of broadband source in center wavelength, and the reflection intensity of Bragg grating FBGa for demodulation is $I_0 R_{FBGb}(\lambda) R_{FBGa}(\lambda)$. The system optical power by received power meter is the FBGa transmission intensity $I_0 R_{FBGb}(\lambda) - I_0 R_{FBGb}(\lambda) R_{FBGa}(\lambda)$ in the frequency range integral, combined with the formula (8) and used the definite integral formula $\int_{-\infty}^{+\infty} e^{-(ax^2+2bx+c)} dx = \sqrt{\frac{\pi}{a}} e^{\frac{b^2-ac}{a}}$ .After the simplification the system optical power is

$$P = \alpha I_0 \int_{-\infty}^{+\infty} R_{FBGb}(\lambda) - R_{FBGb}(\lambda) R_{FBGa}(\lambda) d\lambda$$

$$= \alpha I_0 R_{FBG1} \frac{\sqrt{\pi}}{2\sqrt{\ln 2}} \Delta\lambda_{FBGb} \{1 - R_{FBGa} \frac{\Delta\lambda_{FBGa}}{(\Delta\lambda_{FBGb}^2 + \Delta\lambda_{FBGa}^2)^{1/2}} \exp[-4\ln 2 \frac{(\lambda_{FBGb} - \lambda_{FBGa})^2}{\Delta\lambda_{FBGb}^2 + \Delta\lambda_{FBGa}^2}]\} \tag{9}$$

Where α is the coupling of light energy utilization.

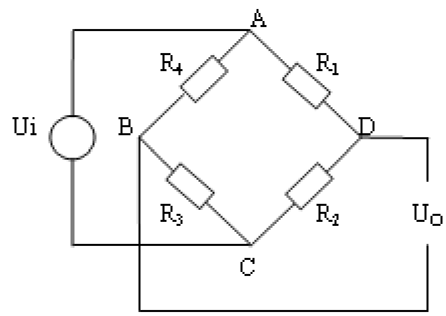

Fig.4. strain electric bridge sensing

Formula 9 includes only two variables, the sensing grating change is caused by environmental temperature in the same direction and caused by the stress change in the opposite direction. Therefore, dual grating structure can eliminate the influence from environmental temperature, only the strain changes manifest in the optical power changes. The demodulation system would make power convert to voltage and displayed, while the strain value can be measured through the strain gauge pasted on the beam surface.

Strain electric bridge transmitter as shown in Figure4. R1, R2 are strain gauges pasted on the beam upper and lower surface. Because of the relative beam position is the same, strain measured is the same, namely the resistance change quantity is the same, and the direction is opposite. If initial R1=R2=R3=R4=R, the strain electric bridge's output voltage can be obtained.

$$U_O = \left(\frac{\Delta R_2}{R} - \frac{\Delta R_1}{R}\right) U_{\mathrm{i}} = \frac{K U_{\mathrm{i}}}{2} \varepsilon \tag{10}$$

And K=ΔR/ε is the sensitivity coefficient, the strain size can be known through measuring bridge's voltage, compared with the grating measured data.

4. EXPERIMENTAL RESULTS

Experimental apparatus as shown in Figure 2, the Incident of fiber Bragg grating monitor connected with FBGa, and covered with shade in the beam to ensure them in the same environmental temperature. Adjusting the micrometer to find the first light intensity change point, namely initial point; through adjusting the micrometer to obtain the light intensity value with corresponding different micro displacement.

When the light intensity does not change with the displacement, this shows that the operating wavelength of two gratings has been separated and has not overlapped area. Because the general power meter is put a light intensity signal into photoelectric current or voltage signal, what is given directly in the experiment is the voltage value.

It can be seen from Figure 5 that experimental data which is measured by both fiber Bragg grating and strain gauge shows a good linear relationship, its sensitivity is the slope of fitting straight line. Left diagram is the relationship curve of displacement and light intensity voltage from fiber grating; another is the relationship diagram of displacement and strain gauge voltage. Because each standard displacement represents 10um, grating sensing for higher sensitivity was 0.87mV/μm; strain gauge sensitivity was 0.12mV/μm.

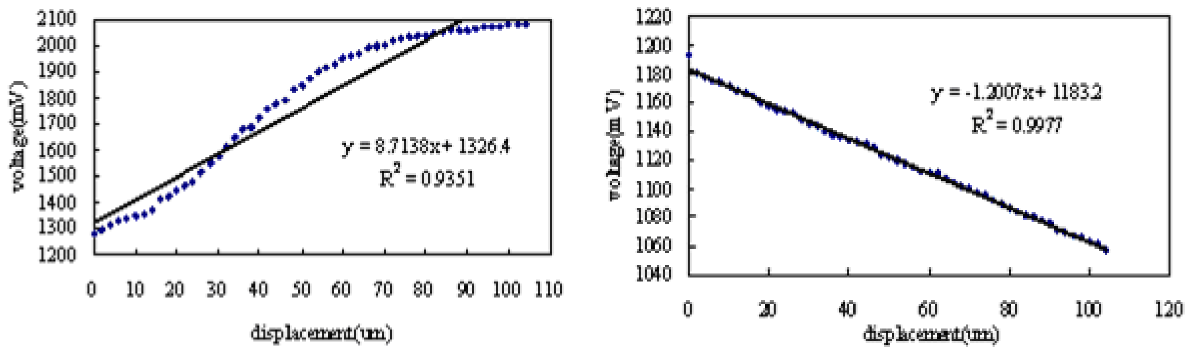

Fig.5. relationship diagram between displacement and voltage

The reasons why there is slight difference between the theoretical value and experimental value are listed below. The movement caused a inclination between micrometer probe and the cantilever free end when deflection loading, resulting in the existence of strain readings errors and the influence from paste quality of the fiber grating.

Load experiment is realized through add weight to the tray, and found the first intensity change point when the load is 10g Set initial position at this time, slowly increase the weight load to obtain different light intensity values corresponding , when light intensity does not along with displacement, that means without overlap area. From Figure 6 can be seen that the sensitivity of fiber Bragg grating was 9.8mV/g in the left diagram, strain gauge measurement sensitivity was 1.06mV/g in the right. The experimental results indicated that compared with the strain gauge, fiber grating can be higher measurement sensitivity.

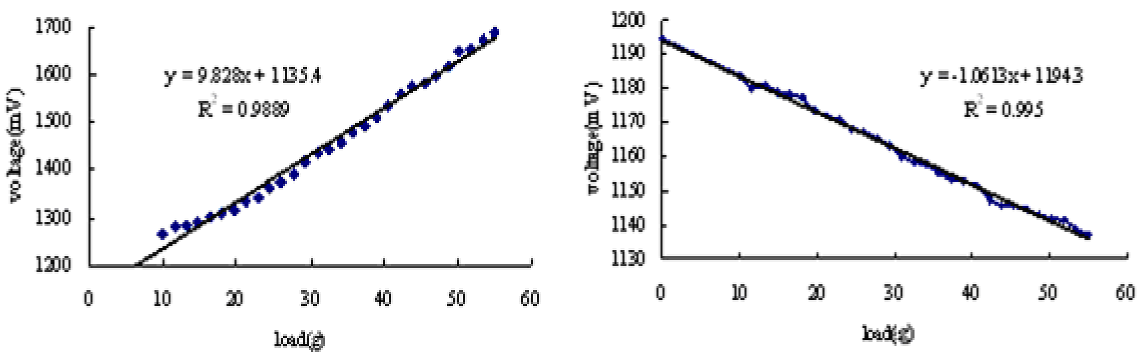

Fig.6. load experiment curves

5. CONCLUSION

This paper mainly introduced the implementation of the structure using grating fiber Bragg grating displacement sensor research, Designed the linear tuning sensitive structure of equal intensity cantilever beam to eliminate influence from environmental temperature, transformed effectively the changes of micro-displacement into the beam strain, Bragg wavelength changes caused by the strain is turned into the voltage value through demodulation system to display, realized micro displacement's optical measurement.

The system is known through calibration that the corresponding relationships of strain and light intensity voltage is 0.56mV/με, the experimental result indicated that system sensitivity is 0.87mV/μm. Displacement measuring range approximately is 1425με by the experimental system, fiber Bragg grating in the wavelength of 1550nm, wavelength shift caused by the stain of 1000με is 1.55nm [9]. Therefore, displacement resolution is 2.12nm/mm.

This demodulation method structure is simple, easy to realize, when the accuracy requirement is not high, it is an ideal testing means, more potential for fiber grating sensing field, which provides the possibility for portable systems development possible.

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