Research of Fiber Bragg Grating Sensor System with Interferometric Demodulation Technique with Lab VIEW

W.G. Qin*[a], Y. Zhang [b]

[a] College of science, Northeast Dianli University, Jilin 132012, P.R.China; [b] Key Lab of Measurement Technology and Instrumentation of Hebei Province, Yanshan University ,Qinhuangdao 066004, P.R.China

ABSTRACT

A new fiber Bragg grating (FBG) sensing demodulation system based on Lab VIEW and the technology of fiber Bragg grating sensing is designed. The system based on unbalanced M-Z interferometer demodulation technique translates the FBG wavelength signal related with the strain in to phase signal and measures the change of the phase with a phase measurement system based on Lab VIEW. With the characteristics of high resolution and wide measurement range, this sensor system has the capability of measuring static strain as well as dynamic strain. Experimental shows that the result of strain tested and theory one have a good linear relationship. The strain sensitivity of the experiment system is 1.2pm/με.

Keywords: Fiber Bragg grating, Sensing signal demodulation, phase measurement, virtual instrument, Lab VIEW

1. INTRODUCTION

In recent years, FBG sensing technology in applications has made great development.[1,2] fiber-optic materials has many advantages, such as small size, light weight, corrosion-resistant, anti-electromagnetic interference, suitable for the effective work in wet and strong electromagnetic radiation adverse circumstances[3 , 4]. Therefore, FBG has been widely used in the large-scale bridges, construction and many other fields. [5 , 6]

How to demodulate the sensing signals effectively and design distributed multiplexing sensing institutions is the key of FBG sensing technology. Demodulating sensing signal and realizing the multiplexing technique has always been the study focus. Know a novel FBG sensing signal demodulation system based on optical unbalanced M-Z interference technology and virtual instrument is designed. The optical unbalanced M-Z interference device translates the wavelength signals coming from the FBG sensors into a phase signal, and then by measuring the phase-change to determine the strain. It has advantages of a high-resolution, large measuring range and small size, and so on. The virtual instrument, as an ideal device, has great superiority in demodulating electricity signals. The anti-jamming ability is not comparable to that of experimental device in physics, and therefore improves the accuracy and sensitivity of the transfer experiment.

2. DEMODULATION SYSTEM AND SENSING SIGNAL DEMODULATION PRINCIPLE

Fig.1 is the Schematic of Fiber Bragg Grating sensing signal demodulation system. Unbalanced M-Z interferometer is based on traditional principle of Michelson interference. The light from the broadband light source go through coupler1 and meet with FBG. The sensing light signal with strain information is reflected by the FBG and goes through coupler1 into coupler2. The sensing light signal is divided into two-way in coupler 2. One enters into the short arm of the optical fiber wrapped around a piezoelectric ceramic which is droved by saw-tooth wave, and the other one into long arm. Two optical signals have interference in the coupler 3, and translated into electrical signals by the photoelectric detector. The electrical signal and saw-tooth wave droved by the piezoelectric ceramic, respectively, as a test signal and reference signal, are put into the phase measurement system. When the two signals have the same frequency, come to the phase change detected by phase measurement system is related to the strain under test imposed on the FBG. The phase difference of the signal under test is expressed in equation (1).

*qin_wg@163.com; zhangy@ysu.deu.cn

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$$\Delta\phi = -\frac{2\pi nL\Delta\lambda}{\lambda^2} \tag{1}$$

Where, n is effective index of the fiber core, L is the arm difference of interferometer, λ is the center reflection wavelength of FBG, $\Delta\lambda$ is corresponding wavelength shift.

At constant temperature, for a strain variation, the corresponding wavelength shift is given by

$$\Delta\lambda = \lambda(1 - P_e)\varepsilon \tag{2}$$

Where, P_e is the effective photoelastic coefficient of the optical fiber, ε is the strain variation. By the equation (1) and equation (2), the strain is given by

$$\varepsilon = -\frac{\lambda}{2\pi nL(1 - P_e)}\Delta\phi \tag{3}$$

Therefore, the phase can be tested, which has a linear relation to the strain, using the phase measurement system, the core of that is virtual instruments (VI).

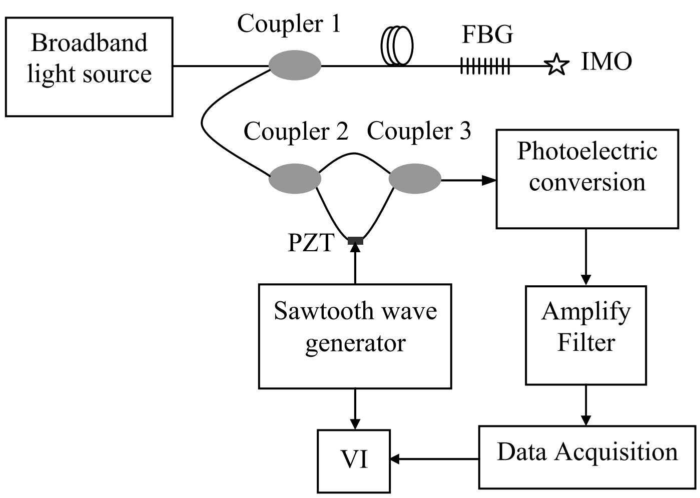

Fig.1. Schematic of FBG sensing signal demodulation system

3. SENSING SIGNAL DEMODULATION WITH LAB VIEW PROGRAMMING

Lab VIEW has become a industry-standard of test and measurement in the field. The actual data acquisition system may be constituted by GPIB, VXI, PLC serial equipment and card data acquisition board. It provides the industry's largest equipment driver library, as well as support data sharing through interactive communication such as the Internet, ActiveX, DDESQL and so on, which provides many development tools so that the complex test and measurement task become very simple. The capability of Lab VIEW, such as powerful hardware drivers, Graphics capability and easy programming fast easily, supplies a good solution for Process control and industrial automation applications. Lab VIEW provides powerful high-level mathematical analysis of the database, including statistics, the estimated regression analysis, linear algebra, signal generation algorithms, time-domain and frequency-domain algorithms and other scientific fields, to meet the needs of a variety of computer and analysis. Even in the joint time-domain analysis, and wavelet digital filter design, or special occasions, Lab VIEW also provided additional specialized software packages.

The light signal from the interference is translated into electrical signal by the PIN photodiode in this system. Then the electrical signals are amplified and filtered, after that, are transmitted into the PC, in order to demodulate it. The virtual instrument using LabVIEW8.2 programming processes the data.

Generally, the approaches of accessing phase include over-zero detection, correlation analysis and spectrum analysis. Spectrum analysis method is used in this system. The principle of spectrum analysis is seeking the corresponding value of the phase in the extraction curve through studying the frequency characteristics of the Periodic signals (mainly phase frequency characteristics), then it can get the phase difference. Actually, we use the Fast Fourier Transform (FFT) for the spectrum analysis. Spectrum analysis has great functions of frequency-select and harmonic suppression.

When the Program runs, it makes use of the diagram 'Am phase Spectrum' in 'Signal Processing Functions' of Lab VIEW, in order to obtain phase frequency characteristics of the signals, therefore, access the phase difference. Through the formula (3), the strain can be calculated. The principle of sensing signals demodulation process and demonstration of sensing signals demodulation process with virtual instrument based on Lab VIEW are shown in Fig.2 and Fig.3, respectively.

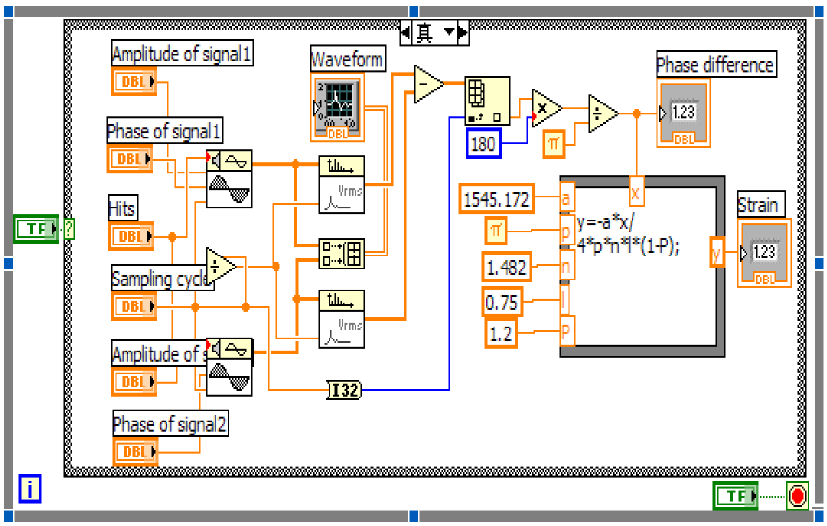

Fig.2. Principle diagram of the demodulation process with the virtual instrument

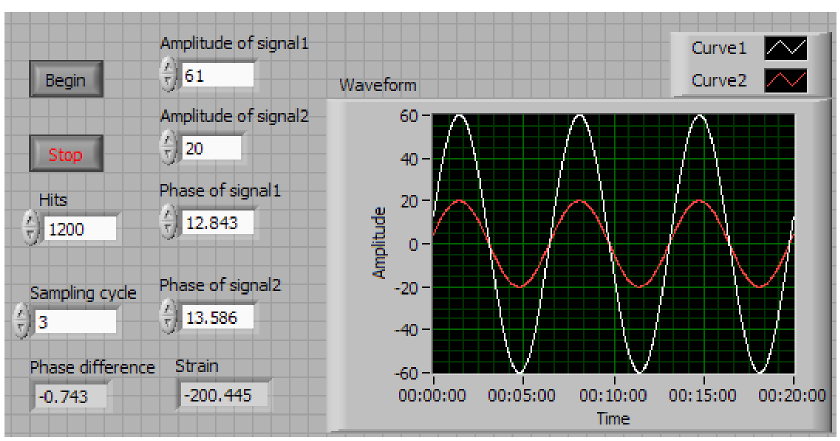

Fig.3. Demonstration diagram of demodulation process with the virtual instrument

4. EXPERIMENT AND RESULTS ANALYSIS

In experiment, the Bragg wavelength of FBG is 1545.172nm, bandwidth of the signal light at 3dB is 0.156nm. Strain tuning device uses triangular uniform strength cantilever beam. FBG is pasted on the central axis of the cantilever without sliding to realize the strain linear tuning through regulating the free end of the cantilever. The effective index of the fiber core is n=1.482, effective photoelastic coefficient of the optical fiber is P_e =0.22, drive frequency of sawtooth wave is 100Hz. The photoelectric detector is InGaAs PIN photodiode, whose diameter is 300μm.

Making strain on FBG, the test data is showed on Table1.

Table1 Data of the experiment

arm difference L(mm)	Wavelength shift $\Delta\lambda$(nm)	Phase difference $\Delta\Phi$(rad)	Theory strain ε_1(με)	Tested strain ε_2(με)
0	0	0	0	0
0.5	0.149	-0.291	123.97	121.38
1.0	0.290	-1.133	240.93	255.65
1.5	0.448	-2.622	371.90	388.43
2.0	0.590	-4.603	489.59	470.30
2.5	0.747	-7.284	619.83	615.58
3.0	0.897	-10.489	743.80	758.76
3.5	1.046	-14.276	867.77	856.78
4.0	1.195	-18.647	991.74	996.73

From Table1, the relation between theory expected value and tested value of strain is showing in Fig.4. Fig.4 demonstrates that the tested strain value is consistent with theory one basically and has a good linear relationship. The deflection between the tested strain value and the theory one is perhaps caused by measurement error of arm difference of the unbalanced M-Z interferometer.

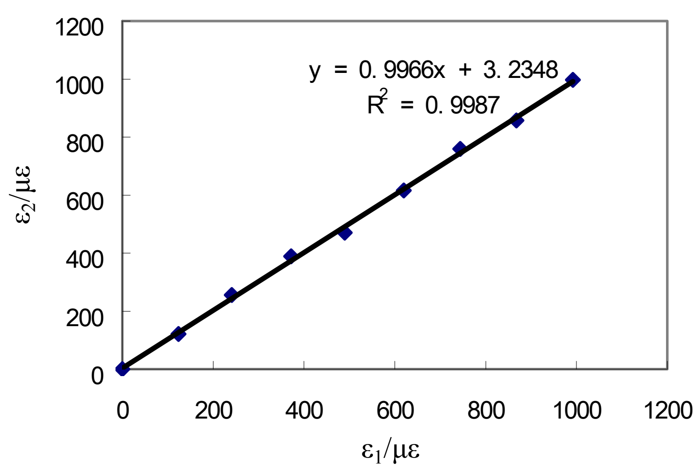

Fig.4. Relation between testing strain and theory strain

5. CONCLUSION

A FBG sensing signal demodulation system based on virtual instrument driven by Lab VIEW programming and optical fiber unbalanced M-Z interferometer is designed. Research and experimental result demonstrate that FBG sensing signal can be measured rapidly and precisely using the system. The system using virtual instrument driven by Lab VIEW programming has many advantages, such as measuring rapidly, higher accuracy, lower cost, easy to operate, full-featured beautiful interface, etc. The system can be applied in the field of measuring strain caused by physical structure change, measuring temperature and other physical quantity measurement.

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