ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 2, February 2016

An Interrogation System for Spectrally Multiplexed Fiber Bragg Grating Sensors

Aswathy C.J[1], Sheela Devi Aswathy Chandran[2]

PG Student [OEC], Dept. of ECE, TKM Institute of Technology, Kollam, Kerala, India[1]

Assistant Professor, Dept. of ECE, TKM Institute of Technology, Kollam, Kerala, India[2]

ABSTRACT: Structural Health Monitoring (SHM) is emerged as a multidisciplinary set of technologies with the goal of reducing maintenance as well as the implementation costs of aircraft structures. By the implementation of automatic load monitoring and damage detection, systems which are able to detect incipient cracks well below the critical size are developed without any human intervention. In recent years, fiber optic sensors particularly those based on Fiber Bragg Grating (FBG) have been proved to be a potentially excellent technique for real-time monitoring of these structures. In this paper, a FBG interrogation system based on an intensity demodulation and demultiplexing of an arrayed waveguide grating (AWG) module is analyzed. The main benefit of this system is it has no moving parts; hence the speed of operation can be very high. The sensing element is configured in reflecting mode and is illuminated by a broad-band light source through an optical fiber. The output spectrum of the sensor is analyzed using an arrayed waveguide grating device containing integral photodetectors. From this the strain and temperature are monitored.

KEYWORDS: Arrayed Waveguide Grating (AWG), Fiber Bragg Grating (FBG), interrogation system, Structural Health Monitoring (SHM).

I. INTRODUCTION

Structural Health Monitoring (SHM) concepts help the aircraft operators to extend the service life of air platforms without increasing the system cost and complexity. The exploitation and implementation of SHM tools are expected to replace schedule-based inspections to reduce the platform life cycle cost, improve safety and reliability and extend operational life cycle. A wide range of embedded and attached sensors are used for SHM applications. Among them fiber optic sensors are used due to their unique advantages such as sensitivity and multiplexing capability. Load monitoring and damage detection are two critical aspects of SHM. Currently load monitoring is performed either by means of electrical strain gauges or by strain sensors. Due to certain limitations of above mentioned methods fiber optic sensors are used [1].

Optical fiber sensor technology is an extremely promising and fast growing technology. Today, fiber optic sensors have become essential device for process control in measurement systems, finding countless applications in factory automation, the automotive industry, telecommunications, computers and robotics, environmental monitoring, health care, and agriculture. The key motivating factors in the development of fiber optic-based systems include the desirability of producing sensors that are light weight, small, immune to EMI, and that require no electrical power at the sensing point.

FBG sensors received broad attention because of their versatile applications in strain, temperature and pressure measurements. In re-usable launch vehicles to ensure structural safety, integrity and durability, intelligent health monitoring systems are essential. Fiber Bragg Grating (FBG) sensors represent a promising solution for structural monitoring of air platforms because they are suitable for multi parameter sensing.

Today various FBG interrogation techniques have been demonstrated [2], [3] and the most successful among them are scanning Fabry-Perot [4] or acoustic filters [5], tuning lasers[6] and CCD spectrometers [7][8][9]. These systems achieved a typical measurement resolution in the range of 0.8μ strain or 1pm. But they suffer low accuracy due to the wear of mechanical actuators. Also its complex nature and hybrid construction raise the cost of the interrogation unit.

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In this paper we propose an arrayed waveguide grating to interrogate FBG sensors. These devices have several advantages over the previously demonstrated systems. This includes solid nature, compact size, immunity to EM interference and passive nature. In the following sections we present a detailed description of proposed system theoretically as well as experimentally.

II.THEORY

2.1 FBG Sensors

One of the most commonly used and broadly deployed optical sensors is the fiber Bragg grating, which reflects a wavelength of light in response to the variation of temperature and or strain. FBGs are constructed either by means of holographic or phase mask method.

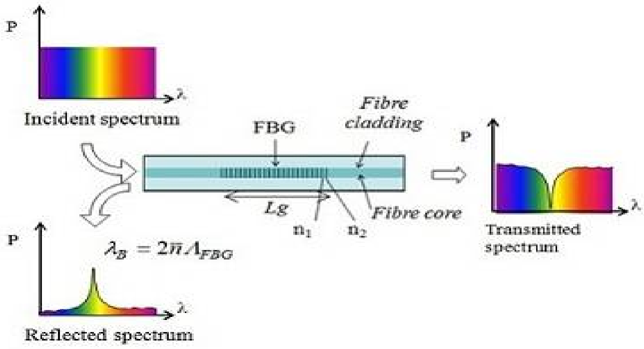

Fig. 1 Principle of FBGs

The fig. 1 shows the basic principle of FBG sensors. When a broadband light is coupled to a single mode optical fiber with an inscribed Bragg grating, a particular wavelength of light is reflected and remaining are transmitted. That reflected wavelength is the Bragg wavelength and is represented as:

$$\lambda_B = 2n\Lambda \tag{1}$$

where λ_B is the Bragg wavelength of the fiber, n is the effective refractive index of the optical fiber and Λ be the period of grating. The shift in Bragg wavelength ($\Delta\lambda_B$) according to the variation of strain and temperature is expressed as:

$$\Delta\lambda_B = \lambda_B(1-\rho_\alpha)\,\Delta\varepsilon + \lambda_B(\alpha+\xi)\,\Delta T \tag{2}$$

where ρ_α, α and ξ are respectively the photoelastic coefficient, thermal expansion coefficient and thermo-optic coefficient of the fiber, $\Delta\varepsilon$ is the strain change and ΔT is the temperature change.

2.2 AWG Operation

Arrayed waveguide gratings are basically planar light wave circuits used commonly as an optical demultiplexer in DWDM systems. The schematic of an AWG configured as a demultiplexer is shown in the fig 2. They have the capability of multiplexing large number of wavelengths in a single optical fiber, thereby increase the transmission capacity of the optical network. The AWG demultiplexer consists of two planar waveguides. When light from a broadband source is entered into the input waveguide it diffracts into the waveguide array. The waveguide arrays are

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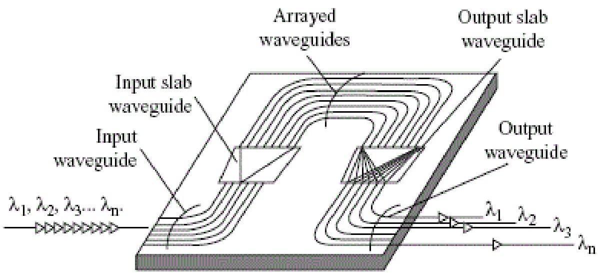

Fig. 2 Arrayed waveguide grating.

designed in such a way that the optical path length difference between the adjacent channels do not interfere with each other. The position and spacing between output waveguides determine the output wavelength, its spacing and the center frequency.

2.3 Interrogation System

A practical fiber-optic sensing system must include a suitable opto-electronic unit to interrogate the FBGs. This unit is used to analyze the wavelength of light reflected and/or transmitted from the fiber optic sensors. Fig. 3 represents the basic schematic of an interrogation system.

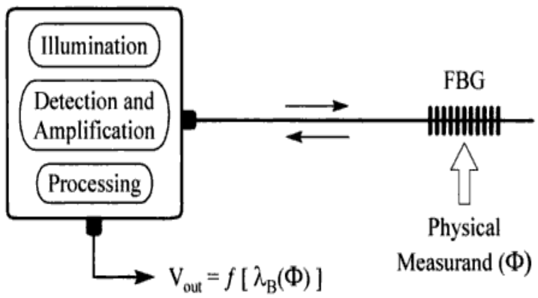

Fig. 3 Interrogation system.

III. SENSOR INTERROGATION SYSTEM

The entire sensing system is shown in the fig. 4. The proposed system consist of a broadband SLD source, an optical circulator, optical channel monitor (OCM) which consist of a 1 x N arrayed waveguide grating based demultiplexer and an array of photodetectors, analog to digital converter and a data processor. Multiple FBGs are installed in a long single mode optical fiber. Light from the broad band source is coupled in to a cluster of FBGs by means of a circulator and the reflected lights are coupled back into the AWG. Each channel of the AWG is detected by a photodiode.

Here we take the analysis of wavelength shift according to the variation of temperature and strain. Let as assume that k and $(k+1)$ (where $1 \leq k \leq N\text{-}1$) be the central wavelength of two adjacent AWG channels. When the Bragg wavelength of FBG is in the middle of the central wavelength of adjacent channels of AWG then the optical power received by k^{th} and $(k+1)^{th}$ detectors are always same. When the FBG temperature changes then the Bragg wavelength of FBG will shift. For data evaluation the ratio of transmission power of AWG channel output is required and it is given as:

$$s = \frac{(I_2 - I_1)}{(I_2 + I_1)} \qquad (3)$$

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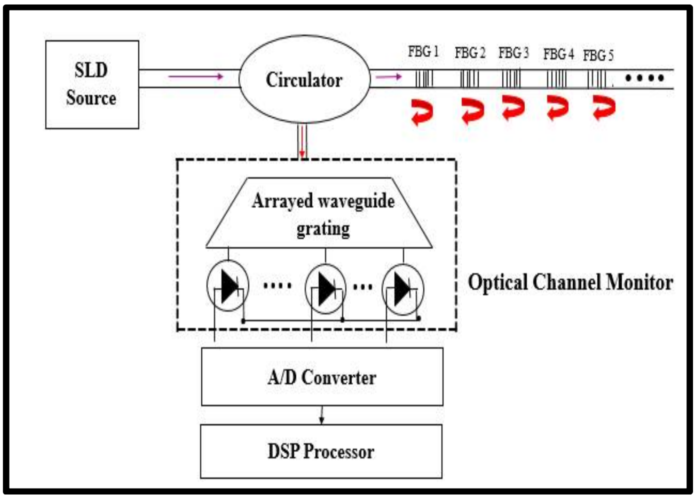

Fig. 4 Distributed FBG sensor system using arrayed waveguide grating for wavelength interrogation.

where the ratio S is the difference to sum ratio of the light intensity of the photodiode corresponding to the two adjacent AWG channels. Here I_2 and I_1 are the light intensity of the photodiode corresponding to the two adjacent AWG channels. Each value of S is related to the Bragg wavelength according to the logarithmic function:

$$\lambda = \lambda_0 + d\lambda.\ln\left[\frac{(A_1 - S)}{(S - A_2)}\right] \quad (4)$$

in which λ_0 is the center wavelength between two adjacent AWG channels. The calibration parameters A_1, A_2 and $d\lambda$ depend on the spectral profile of FBG sensor.

IV. EXPERIMENTAL EVALUATION AND RESULTS

The measurement system shown in the fig. 5 is setup in the laboratory. The optical source used is an Exalos based super luminescent diode (SLD) with a full width half maximum (FWHM) of 60nm. Its output spectrum is shown in the fig. 5. This broadband light passes through a series of FBGs and the reflected spectrum is shown in the fig. 6. Table 1 shows the spectral characteristics of FBG sensors.

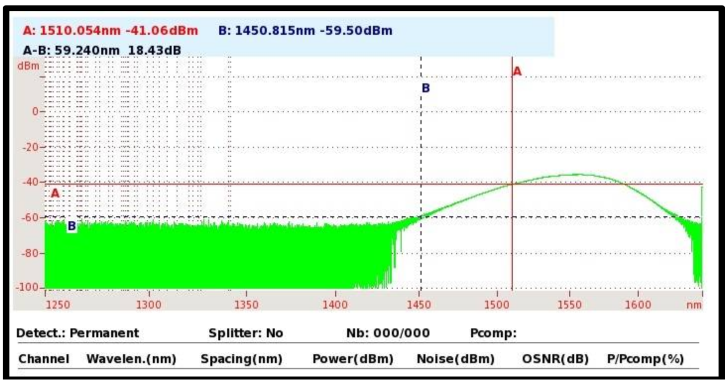

Fig. 5 Output spectrum of SLD module.

The determination of calibration parameters of AWG based module can be done by strain induced or temperature

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induced wavelength shift. For temperature testing the FBG sensor is kept in a temperature chamber and by changing its

Fig. 6 Output spectrum of five different FBG sensors.

temperature, wavelength shift occurs. This shift in Bragg wavelength is simultaneously recorded by both the spectrometer and AWG-based interrogator. For latter mentioned system, the ratio S is determined from the photodiode signals corresponding to adjacent AWG channels and is related to the wavelengths obtained by the spectrometer. The

Channel	Wavelength(nm)	Spacing(nm)	Power(dBm)	Noise(dBm)	OSNR(dB)
1	1530.108		-33.93	-54.77	20.75
2	1534.075	3.967	-33.42	-54.39	20.84
3	1539.890	5.791	-33.15	-53.64	20.31
4	1549.143	10.004	-32.59	-53.33	20.59
5	1560.80	10.560	-35.5	-53.00	17.40

Table 1. Spectral characteristics of FBG sensors.

calibration parameters are obtained by fitting a curve to the measured data. And the curve is shown the fig. 7. The shift in Bragg wavelength can be calculated by the Eqn: (4).. Similarly strain induced wavelength shift is also obtained with the help of a cantilever beam.

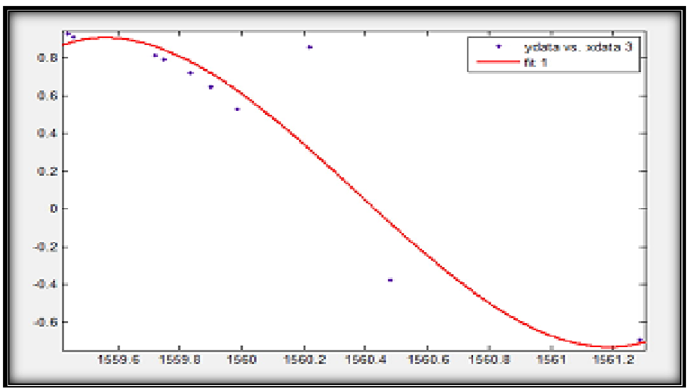

Fig. 7 Determination of calibration parameters by fitting a curve to the Bragg wavelength recorded by the spectrometer. In this case the parameters are exemplary: A_1=0.95, A_2=-0.07, $d\lambda$=0.2nm and λ_0= 1560.2nm (central wavelength between two AWG channels).

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V. CONCLUSION

SHM is emerging as a vital tool to help engineers to improve the safety of critical structures. Fiber Bragg Grating sensors are suitable for launch vehicle health monitoring mainly due to the advantages such as multiplexing capability and high resolution. In this paper a system in which AWG is used as an interrogation component for demodulating the fiber Bragg grating sensors is demonstrated. This system measure the wavelength shift of FOS due to temperature and strain. AWG-based DWDM type spectral elements combined with array of detectors provide a solution to parallel processing so that the response speed is largely increased.

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BIOGRAPHY

Aswathy C J received her B Tech degree in Electronics and Communication Engineering from Cochin University of Science and Technology in 2014. She is currently pursuing second year M Tech in Optoelectronics and Communication systems at TKM Institute of Technology.

Sheela Devi Aswathy Chandran received her B Tech. degree in Electronics and Communication Engineering from Cochin University of Science and Technology in 2009 followed by M Tech in Industrial Instrumentation and Control from University of Kerala in 2011. She is currently working as Assistant Professor in Department of Electronics and Communication Engineering at TKM Institute of Technology.