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Temperature Controlled SLD Source for Spectrally Multiplexed FBG Sensors

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ABSTRACT: Structural health monitoring is the science of analyzing the various parameters that influence the performance of an aircraft in real time. An aircraft should provide with proper temperature and strain adjusting mechanisms since it has to face vigorous environmental fluctuation during flight and only a proper monitoring and adjustment can keep the space craft healthy. The temperature and strain being the prime factors, earlier SHM systems used the conventional bulky sensors to evaluate these changes. With the advancements in optical technologies, conventional sensors are replaced by fiber optic sensors, a major category among them being the Fiber Bragg Grating (FBG) sensors, made by inducing periodic refractive index fluctuations in the fiber core. They are effective in measuring very minute temperature and strain fluctuations and a large number of them can be incorporated into a single optical fiber. The main adversity that the structural health monitoring systems face is the lack of a proper source system, which is capable of providing light with the required power to the Fiber Bragg Grating sensors. The existing systems are laser having a very narrow spectral response and light emitting diodes (LED) that cannot withstand hostile environments. Since the prime requirement of an FBG sensor system is a proper source, the development of a new and improved superluminescent diode based optical system is proposed and its characteristics when used to illuminate Fiber Bragg Grating sensors are studied. It has proper thermal management and it provides the maximum output power. The temperature controlling is done by a peltier cooler incorporated along with the SLD and thereby it avoids the thermal worn-out of the source. It is found that the new SLD source system can be a better replacement for the current sources used especially in the field of aircraft structural health monitoring due to the higher bandwidth it could achieve than the conventional sensors.

KEYWORDS: Superluminescent Diode (SLD), Fiber Bragg Grating (FBG), Structural Health Monitoring (SHM).

I. INTRODUCTION

Process of damage detection and characterization strategy for structures and its implementation is known as Structural Health Monitoring (SHM). In SHM, changes to the material or geometric properties of systems, which adversely affect the systems performance, is defined as damage. The SHM process involves the observation of a system over a long period using periodically sampled data measurements from sensor systems in real time, the identification of damages from the measurements, and the analysis of these features to determine the current state of system health. For long term SHM as in aircraft applications, the output of this process needs to be updated at each instant of time for information regarding the reliability of the structure to perform its function knowing that there is an unavoidable process of aging and degradation due to operational ambient and wear and tear.

One of the most commonly used and broadly available optical sensors in SHM is the fiber Bragg grating (FBG), which reflects or transmits (according to the type of FBG) a wavelength of light, and the light gets shifted due to variations in temperature and/or strain. FBGs are constructed either by using holographic interference or by a phase mask in order to expose a short length of photosensitive fiber to a periodic light intensity variation. The refractive index of the fiber core is permanently changed in accordance with the intensity of light used. The resulting periodic variation in the refractive index of fiber core is called a fiber Bragg grating.

When a spectrum light is sent to an FBG, reflections from each grating of alternating refractive index appear to interfere constructively, only for a specific wavelength of light, called the Bragg wavelength represented mathematically as,

$$\lambda\ (b) = 2n\Lambda.$$

where λ (b) is the Bragg wavelength, n is effective refractive index of the fiber core and Λ is the wavelength of light.

II. LITERATURE SURVEY

The existing systems for SHM use the conventional sources of LASER and light emitting diode for illuminating the FBG sensors. The narrow spectral response of LASER is not suitable to illuminate a large number of sensors while cavity resonators are having moving parts which is not suitable for space craft applications[1][5]. LEDs have wider spectral response than the Laser source, but are still not convenient for space applications since they cannot withstand the vigorous ambient conditions [11]. H. J. Patrick et.al [9] proposed that the FBG is advantageous due to the ability to measure very small wavelength shifts. There are various parameters like strain, temperature, humidity etc. that can be sensed by FBG sensors [6]. But the available receiver configurations are unable to distinguish the small wavelength shifts. Long period grating sensors are used for the distinguishable measurement of different parameters. Edge emitting laser diode is used here as the light source since they are capable of providing a better spectral response than normal laser diodes.

Yasukazu Sano et.al [10] proposed that the key technology for the FBG sensors is the interrogation of wavelength shift. Interrogation schemes such as Fabry Perot interferometer, fiber optics, Lithium Niobate crystals are used in various fields. Junhao Hu et.al[2][4] proposed that due to noise and loss introduced by Rayleigh scattering and attenuation along the fiber, maximum transmission distance of a broadband source is limited to 25km. For long distance sensor system based on FBG, high power pump light is required to produce amplified spontaneous emission (ASE). But these large power levels cause the transmission single mode fiber (SMF) to act as a laser cavity. P. Niewczas et.al [8] proposed that the introduction of WDM and DWDM technologies fastened the growth and development of optical communication. More than 10Tbits/s capacity is its most attracting feature. J.H. Lee et.al [7] proposed that the FBG sensors can be used for a wide range of sensing applications. But it has the practical issue of transmission distance [3]. To increase the transmission distance, several approaches of transmission distance like pump recycling etc. are used.

Here in this work, an advanced source system with superluminescent diode having superior qualities than the conventional sources is proposed and its characteristics are experimentally evaluated. It is a simple system without additional circuits to enhance the performance. Since the system can withstand adverse temperature conditions, hostile environments other than aircraft monitoring like mining fields can also be evaluated with this technology. Installation of the system is a costly purpose but maintenance cost is much low for optical systems.

III. EXPERIMENTAL SETUP

The spectral response from an SLD is plotted on the optical spectrum analyzer (OSA) and the characteristics of the response are studied initially. The optic fiber having grating structures incorporated within its core is illuminated from the tested source and the reflected spectrum is evaluated. The test setup is shown in figure.1. Each FBG sensor is manufactured in such a way to reflect only a desired wavelength of light, and here the fiber under test consists of five FBG sensors. The whole system is tested under varying temperature ambience and then tested for varying strain conditions to it in order to analyze temperature vs. wavelength, strain vs. wavelength and sensitivity of the device under varying temperature and strain conditions.

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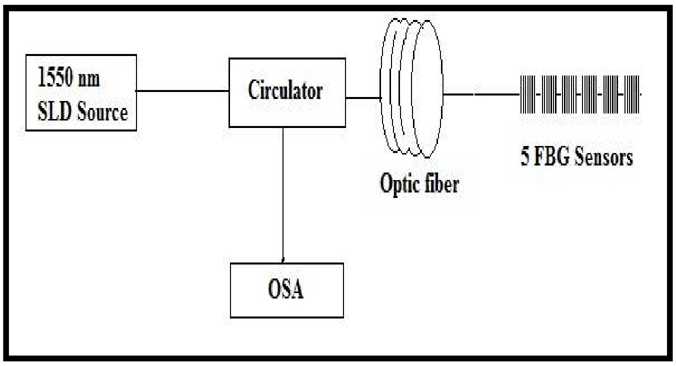

Figure.1. Experimental setup

The response from an SLD source is of Gaussian nature and since the source here is of 1550nm the emission peak is centered on the peak value of 1550nm. The figure.2 shows such a Gaussian output spectrum obtained on the optical spectrum analyzer with a bandwidth range of 45-60nm.

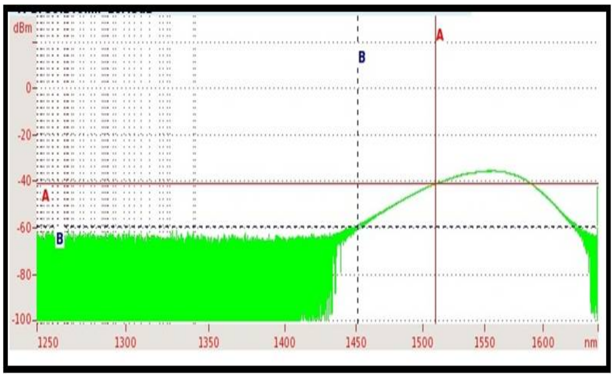

Figure.2. Gaussian response from SLD

A broader spectral response compared to the conventional sensors is clearly attained by the use of superluminescent diode. But there is prominent effect of noise in the output Gaussian spectrum, which could be eliminated by the use of an SLD driver circuit. Driver circuit controls the current flow to the SLD. It also helps in the power stabilization of output spectrum. Optical sources when used for long time are prone to the temperature effects and hence there is a chance of source damage. In systems where a replacement option is not available, this is a serious problem. The source damage due to increased temperature is avoided by the use of Peltier cooler, associated with the source and a proper driver circuit is provided to Peltier cooler also for its effective working.

IV. WORKING

Instead of powering the SLD directly, here an alternative is provided, that is powering via a driver circuit. The advantages of using the driver is that the vulnerability of damage to source due to over current is avoided to a great extent, since the driver provides only a power regulated, voltage controlled output. It is very much important in the case of aircraft structural health monitoring, since in the long term flights, the source should remain as such, that is without any change in characteristics to the maximum time possible. By using the driver, not only power stabilization, but also reduction in noise level is also obtained. The noise reduction improves the purity of the spectrum and hence the FBGs can be effectively illuminated. An FBG with Bragg wavelength of 1560.431 nm is tested here.

It is possible to analyze the two parameters of the source system and they are temperature effect on the wavelength, which is shift in wavelength on temperature fluctuations and the sensitivity (the weakest change that can be detected). High sensitivity is necessary since it increases the reliability of the system.

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The aircraft is under fluctuating temperature conditions while it is under flight and this affects the source adversely. The under flight ambient conditions are made possible with the help of temperature chamber or heat chamber. It is possible to evaluate temperatures ranging from -10°celcius to 120°celcius. Strain measurement is carried out with the help of a cantilever beam. Strain changes with applied weights ranging from 0-110 με are done on the system.

A Peltier cooler is associated with the source to control the heat emitted during the working of the source and it acts like a heat sink. It is controlled by an external controller/driver circuit. Due to the timely action of the cooler, the long life of source despite extreme temperature conditions is assured.

V. RESULTS AND DISCUSSION

The evaluation system shown in figure.1 is setup in the laboratory. The normal output Gaussian spectrum without any associated circuits (no stabilization) is shown in figure.2 and has visible effects of noise. It is reduced to the maximum possible extent by the use of driver. This reduction in noise by the use of driver is clear from the comparison of figure.2 and figure.3. The spectral purity enhancement by the implementation of driver helps to improve the sensitivity of the sensor system. Another notable feature of the SLD source used here is the increased power output. The power of about 10mw is obtained from the SLD source which is far improved than the existing sources.

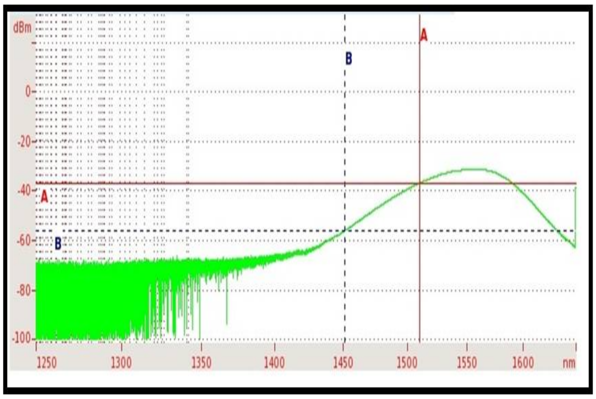

Figure.3. Gaussian response from SLD with a driver

The temperature change in the environment has a noticeable effect on the wavelength response obtained from the system. As the temperature increases or decreases the wavelength has a linear change either positively or negatively. It is experimentally proven and the result of the experiment is shown in the figure.4.

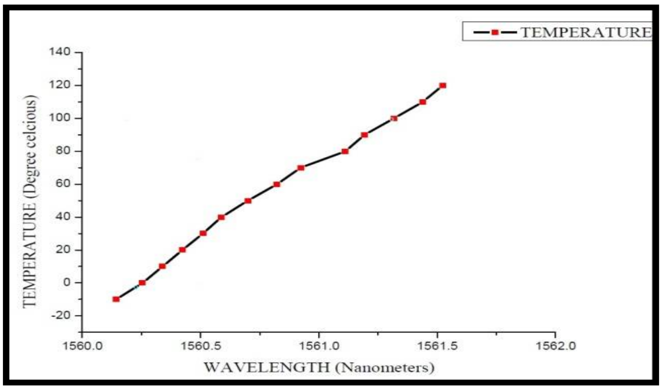

Figure.4. Linear variation of wavelength with temperature

The experimental result matches perfectly with the theoretical evaluation of the response of SLD to temperature fluctuations. For space craft applications, the temperature sensitivity of the system should be a high value, so that slight variations can also be traced. The sensitivity vs. temperature characteristics is traced and it is shown in figure.5. It is clear that the sensitivity range remains within the expected theoretical range and the source is hence can be used for applications demanding higher sensitivity.

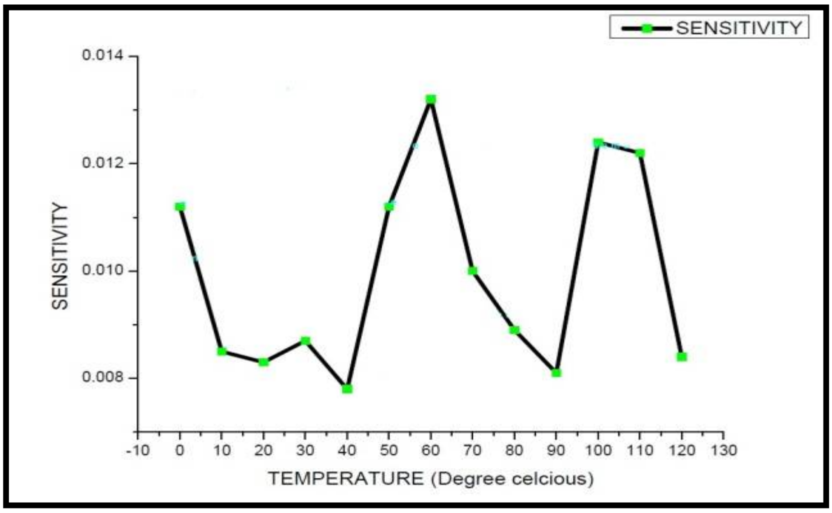

Figure.5. Sensitivity with temperature of SLD

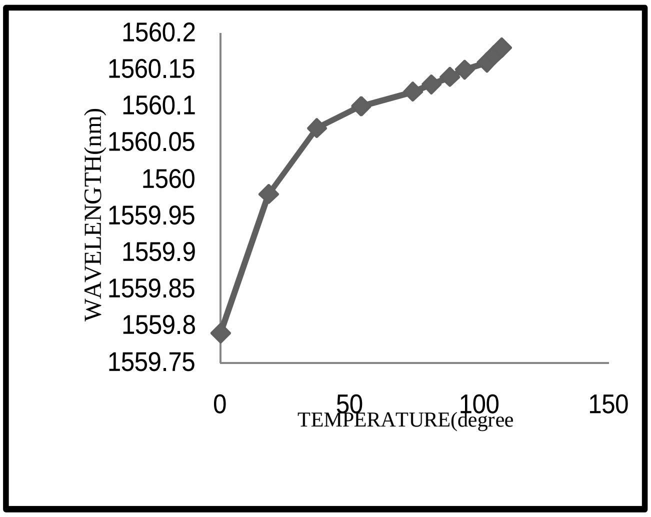

Figure.6. Linear variation of wavelength with strain

Theoretically it is found that the applied strain or pressure fluctuations in the environment correspond to the back reflected light from the FBG sensors. This variation of wavelength with strain is said to be linear and this is obtained experimentally as shown in figure.6. The increase or decrease in applied strain has the corresponding positive or negative impact on the wavelength response. As in the case of temperature evaluation, sensitivity characterization in the varying strain ambience is also a factor of consideration.

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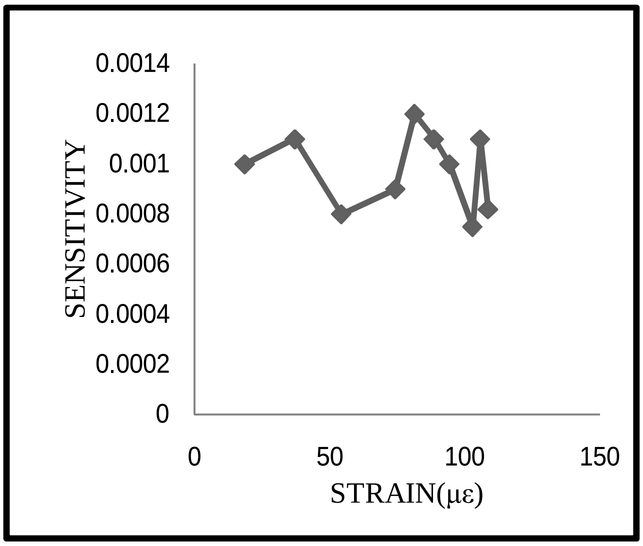

Figure.7. Sensitivity variation with strain of SLD

The sensitivity of FBG sensor with strain fluctuation is plotted in figure.7. The high value of sensitivity is clearly visible from the figure.

VI. CONCLUSION

The development of an effective source for spacecraft structural health monitoring is described in this paper. The source system used is a superluminescent diode (SLD), which incorporates features of existing LASER and LED sources, but have improved features compared to conventional sources. Using the SLD as source along with driver circuit and a peltier cooler, a power stabilized, temperature controlled output spectra is obtained. When it is used to illuminate Fiber Bragg grating (FBG) sensors for evaluation of temperature fluctuations, a perfect linear response is obtained and sensitivity of the system is high in the range of about 13 pico meter. The strain a characteristic of the SLD is also came out to be a perfect one. A maximum possible sensitivity of 1.2 pico meter is experimentally obtained and it perfectly suits for spacecraft applications since minute strain can also be detected. Temperature controlling helps to increase the lifespan of the source also.

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BIOGRAPHY

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