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A Method to Measure Reference Strain in FBG Strain Sensor Interrogation System Involving Actuators

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A method to measure reference strain in FBG strain sensor interrogation system involving actuators

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Abstract

A method for reference strain measurement for FBG strain sensor in the testing stage while applying strain using actuators like piezo translators or micro screw is introduced. Unlike conventional methods of surface mounting, in our method the strain gauge is affixed directly to the optical fibre, which allows it to use with systems where the strain is applied directly using actuators while testing the FBG sensing system. Different bonding techniques were tested and a comparison with the results from calculated values are presented. Since the contact area between the fibre and strain gauge is very small a corrected gauge factor is calculated and is used to measure the strain transfer. As a demonstration of the developed method, the strain gauge is used as a reference in an edge filter based FBG sensors interrogation system, where the strain was applied using a micro screw. The measured strain using foil strain gauge affixed to the optical fibre and FBG sensor interrogation system are in close agreement.

Key Words: Strain gauge, Gauge factor, Reference strain, FBG

1. Introduction

Strain measurements based on FBG is a rapidly developing technology which is driven by its performance accuracy and versatility and is being used for structural monitoring and smart structure applications [1, 2]. Before using it for different applications, the FBG demodulation system has to be tested in the laboratory. In conventional method the foil strain gauge [3] often serve the purpose of a reference to FBG strain sensor, where both the FBG and strain gauge is surface mounted to a structure where the strain is applied [4]. By the introduction of actuators like piezo translators and micro screw, strain can be applied directly to the optical fibre contains the FBG. In this method strain gauge cannot be surface mounted. In order to use the strain gauge as a reference in these cases, it has to be affixed to the fibre directly. In the direct affixing since the contact area is very small gauge factor has to be recalculated to measure the correct strain transfer. In this paper we have explained the details of different method to fix the foil strain gauge directly to the optical fibre and to make it to use as a reference in FBG sensor testing, where the test strain is applied using actuators.

2. Strain measurement using FBG strain sensor system

The basic operation of FBG strain sensor is based on the measurement of the peak wavelength shift induced by the applied strain [5]. The light reflected by periodic variations of refractive index of the Bragg grating having a central wavelength λ_G is given by $\lambda_G = 2n\Lambda$, where n is the effective refractive index of the core and Λ is the periodicity of the refractive index modulation. When the strain is applied there will be a shift from this peak wavelength, which can be calculated using the relation, $\Delta\lambda_G= \lambda_G$(1-

$\rho_\alpha)\Delta\varepsilon$, where ρ_α is the photo elastic coefficient of the fibre given by [6], $\rho_\alpha = \frac{n^2}{2}\left[\rho_{12} - \upsilon(\rho_{11} - \rho_{12})\right]$, ρ_{11} and ρ_{12} are the components of fibre optic strain sensor and υ is the Poisson's ratio. For silica core fibre the value of $(1 - \rho_\alpha)$ is usually 0.78.

A ratiometric wavelength measurement system with an edge filter [7, 8] can be used to measure the wavelength shift induced by the strain. The schematic of the experimental system to test the FBG demodulation system is shown in Fig. 1. A super luminescent diode was used as a broadband source to interrogate the Bragg grating. An optical isolator was used to protect the diode from the back reflected light. The reflected light from the FBG sensor was directed to an edge filter based wavelength demodulation system, using a 2x2 optical coupler. The peak wavelength of the FBG sensor used was 1560 nm. In the laboratory testing, strain can be applied directly to the FBG by fixing one end of the fiber to a micrometre translation stage or to a piezo actuator. The strain corresponding to the wavelength shift from the peak wavelength of the FBG can be calculated using the above relation. A strain gauge is used as a reference by fixing it directly to the fibre. The bonding methods used to fix the strain gauge to the optical fibre and the comparison results are explained in the next section.

3. Reference in FBG sensor system testing

Conventional method of surface mounting the foil gauge cannot be used while using it with actuators, instead the gauge has to be fixed directly to the optical fibre. In order to use a strain gauge as a practical strain sensor, we must measure the extremely small changes in the resistance with high accuracy, which can be achieved with a Wheatstone's bridge circuit with a voltage excitation source [3]. Different bridge configurations such as full bridge, half bridge and quarter Bridge are commonly used. Full bridge and half bridge circuits are more sensitive to strain than a quarter bridge circuit. However, realization of a full bridge and half bridge in the case of optical fibre is very difficult. Therefore, a quarter bridge circuit is more suitable for fibre strain measurements and was used in our experiments. A data acquisition card NI PXI 6221 controlled by LabView 8.0 was used to acquire data from the gauge amplifier. The value of the strain ε can be derived using the following formula [9], $\varepsilon = \frac{4V_r}{GF(1-2V_r)} \quad (1+\frac{R_L}{R_g})$, where GF is the gauge factor, R_g is the gauge resistance and R_L is the resistance of the wire used and V_r is defined as $V_r = (\frac{V_o}{V_{ex}})_{strained} - (\frac{V_o}{V_{ex}})_{unstrained}$, where V_o is the output voltage of the bridge and V_{ex} is the bridge supply voltage.

3.1 Bonding Methods

Extreme care has to be taken when attaching the strain gauge to the fibre. A two-part fibre optic epoxy resin, part number T120-023-C2, was used as an adhesive. Fig. 2 shows different bonding methods to affix the foil strain gauge to the optical fibre. In method (a) the foil strain gauge was affixed directly to the optical fibre using the epoxy. In order to avoid strain cause by the weight of the strain gauge the setup was placed on a supporting surface. One end of the fibre containing the FBG was attached to the supporting surface and the other end was fixed to the micrometre translation stage. For the strain gauge used here the manufacturer's value of GF was 2. However this value can only be used in the case of full strain transfer where the strain gauge is in complete contact with the surface.

In the case of the small contact area that arises with a foil gauge and fibre, the GF has to be corrected. For a known value of fibre elongation and gauge resistance variation, the corrected gauge factor (CGF) can be calculated from the equation 3.

Corrected Gauge Factor, $CGF = \dfrac{\Delta R/R}{\Delta L/L}$ (3)

where ΔR is the variation in the resistance, R is the gauge resistance, L is the length of the optical fibre and ΔL is the fibre elongation. It should be noted that CGF is dependent on the amount and type of the epoxy used. So extreme care has to be taken in fixing the foil strain gauge to the fibre to keep the CGF always same. The gauge factor calculated using the above equation was 0.32 which is used to calculate the strain from the measured voltage change. For different bonding methods the CGF is different. In method (b) the lower end of the strain gauge is fixed to the support to ensure proper strain transfer. This may be useful for certain physical configurations. The CGF measured in this method was also 0.32, showing that the strain transfer is the same as for the method (a).

In the above two cases the contact area between the strain gauge and the fibre was very small which may limit the transfer of strain to the strain gauge. In order to increase the contact area and the strain transfer, two dark (no light) fibres are affixed to the gauge and the ends of these fibres are bonded to the live fibre as shown in method (c) in Fig. 2. The dark fibres are used to spread the strain across larger areas of the strain gauge. As in the method (b) an alternative method was also tested by fixing the lower end of the gauge to a support which is shown as method (d). But opposite to expectations, in the multiple fibre approach CGF was not measurable because of the poor strain transfer, which is the consequence of the larger quantity of adhesive used to fix the dark fibres, which significantly reduces the expansion of the gauge with the applied strain.

4. Comparison of different configurations

Fig. 3(a) and 3(b) show the strain values for increase and decrease in the fibre elongation for the strain gauge affixed directly (method a) to the fibre and with the lower end of the gauge attached to the support (method b) respectively. Fig. 4 shows the comparison between the calculated values of the strain applied to the fibre and the experimental value obtained using different bonding techniques. It was found that the first two methods [(a) and (b)] are in good agreement with the calculated values. For strain values over 500με, the peak error was 3.13 % for the method (a) and 10.04 % for the method (b). Thus we can conclude that the method (a) Fig. 2 is superior. In the multiple fibres approach [method (c) and (d)] GF was not measurable and hence strain was not measured.

Method (a) is used as a reference in FBG sensor with edge filter demodulation system where the strain is applied using a micrometre translation stage. A comparison result of strain measured using the FBG strain sensor and the foil gauge reference strain sensor is shown in Fig 5. The strain measured by using the strain gauge and the FBG sensor shows a good agreement with the calculated strain. Thus for system's involving actuators for applying test strain, strain gauge can be directly attached to the optical fibre to use it as a reference by knowing the corrected gauge factor.

5. Conclusion

A method to measure reference strain using foil strain gauge by fixing it directly to the optical fibre which can be used while testing the FBG sensor system involving actuators like piezo translators or micrometre translation stage is demonstrated successfully. The experimental results show the strain measured by strain gauge was very close to the strain measured by the FBG sensor and the calculated strain. By testing different methods of bonding the fibre to the strain gauge it is clear that, the gauge factor, which is the measure of the sensitivity of the gauge, depends on the way it is bonded to the fibre. Research to estimate the influence of different epoxies on strain transfer and other characteristics is underway.

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Figure Captions

Figure 1. Schematic of an FBG strain sensor interrogation system

Figure 2. Different methods to fix the foil strain gauge to the optical fibre

Figure 3. Measured reference strain using (a) method a and (b) method b

Figure 4. Comparison of different configurations with calculated strain

Figure 5. A comparison of the strain measured by reference strain gauge and FBG sensor with the calculated strain

Figure 1

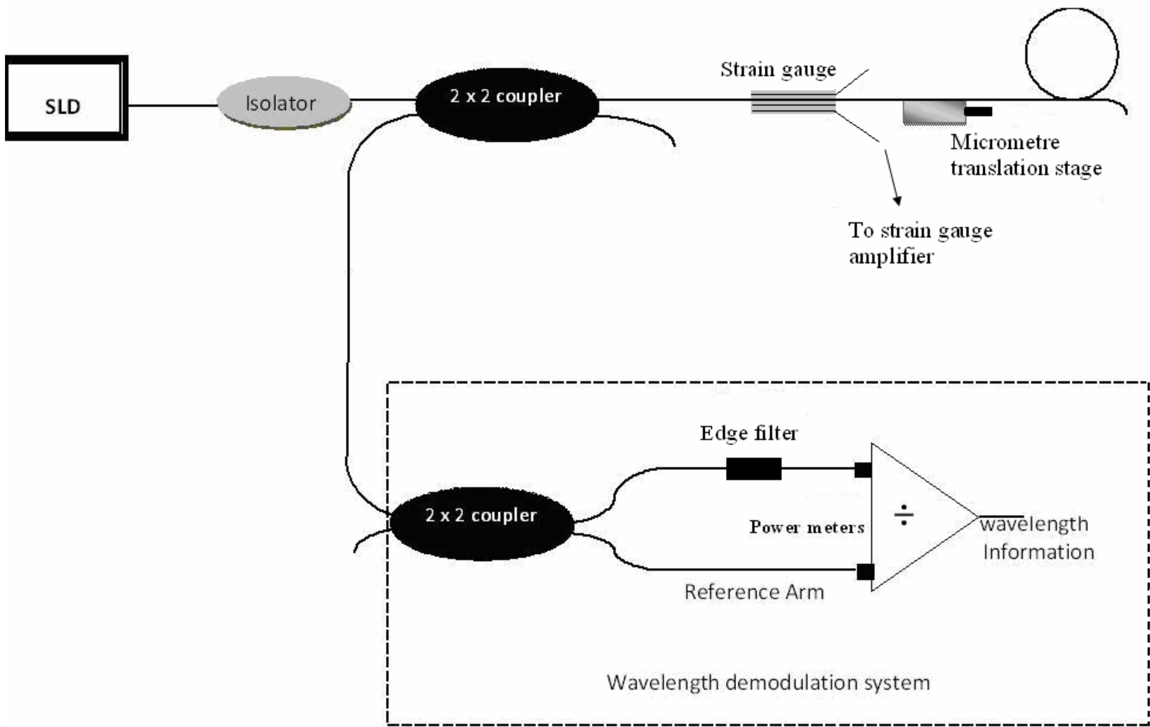
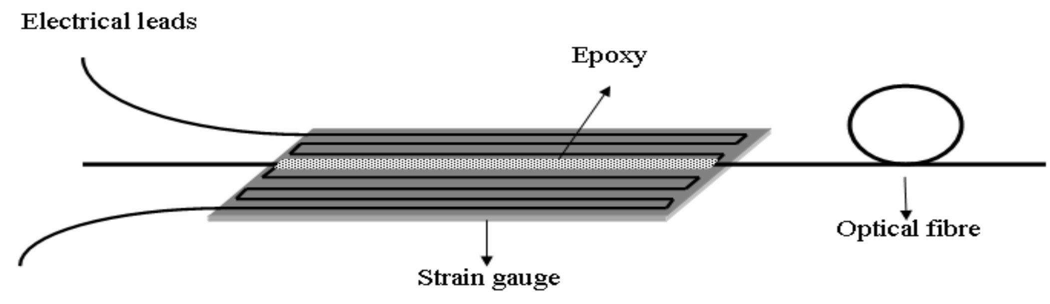
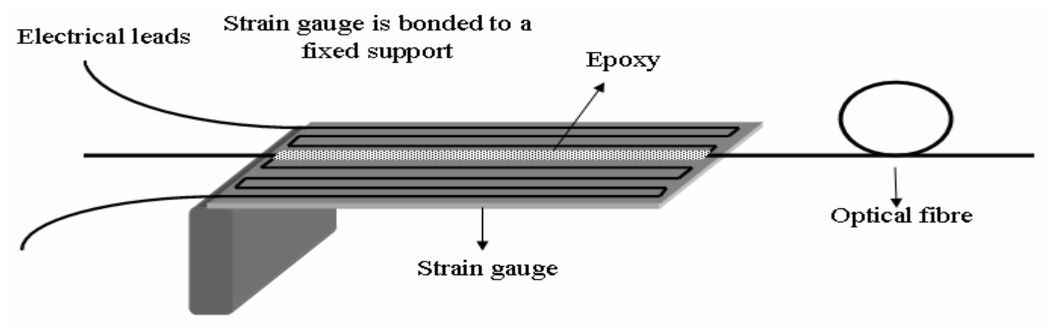

SLD
Isolator
2 x 2 coupler
Strain gauge
Micrometre translation stage
To strain gauge amplifier
Edge filter
2 x 2 coupler
Power meters
÷
wavelength Information
Reference Arm
Wavelength demodulation system

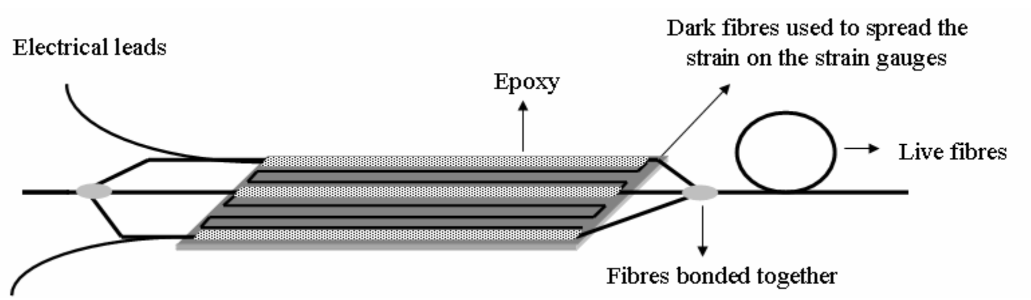
Figure 2



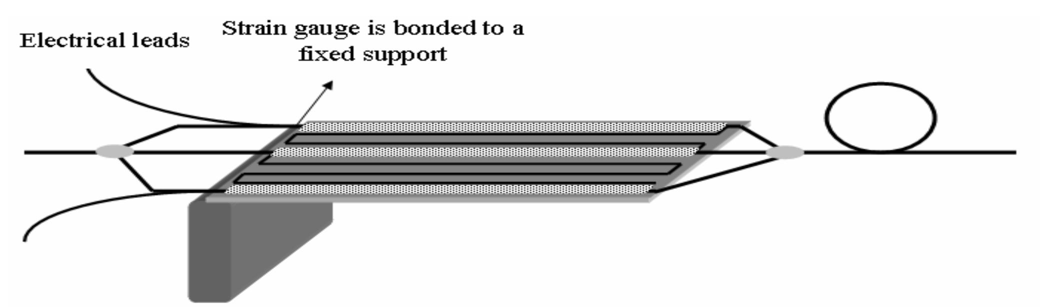
(a)



(b)

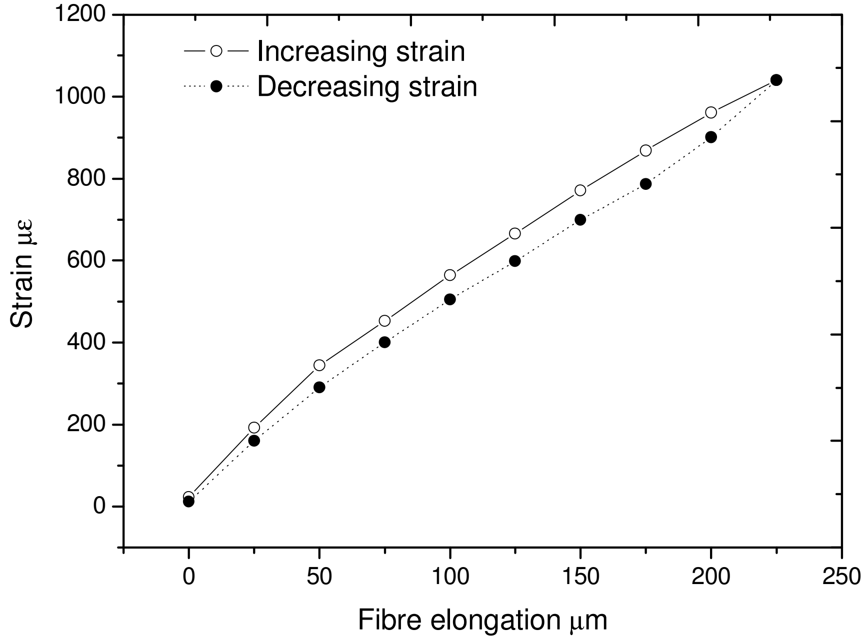


(c)



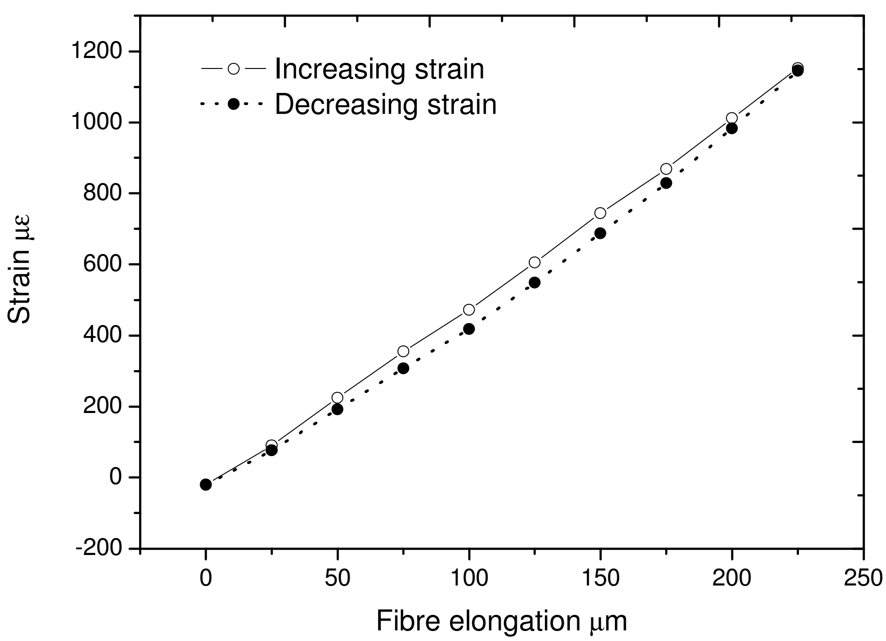
(d)

Figure 3



1200
1000
800
600
400
200
0
0
50
100
150
200
250
Strain με
Fibre elongation μm
Increasing strain
Decreasing strain

(a)



1200
1000
800
600
400
200
0
-200
0
50
100
150
200
250
Strain με
Fibre elongation μm
Increasing strain
Decreasing strain

(b)

Figure 4

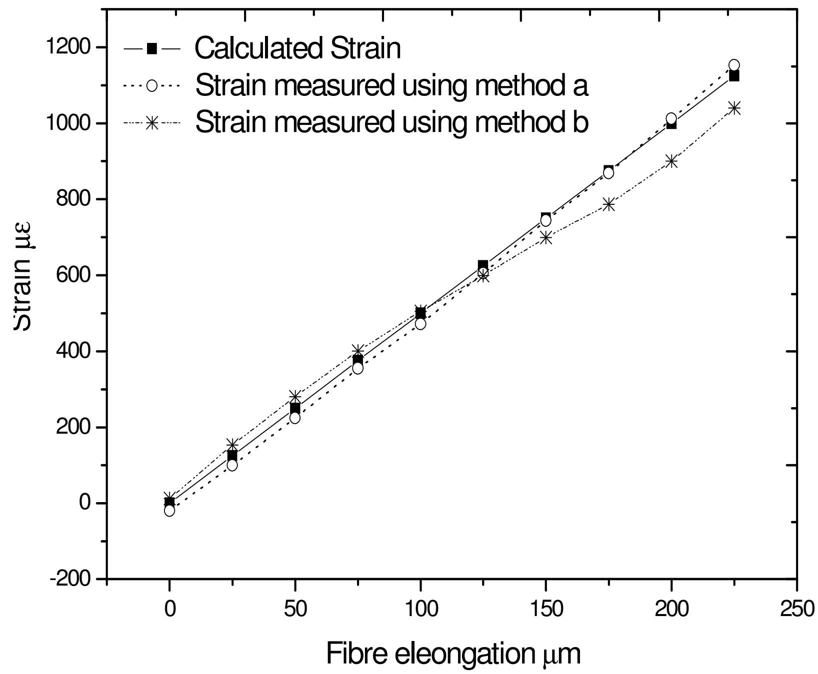
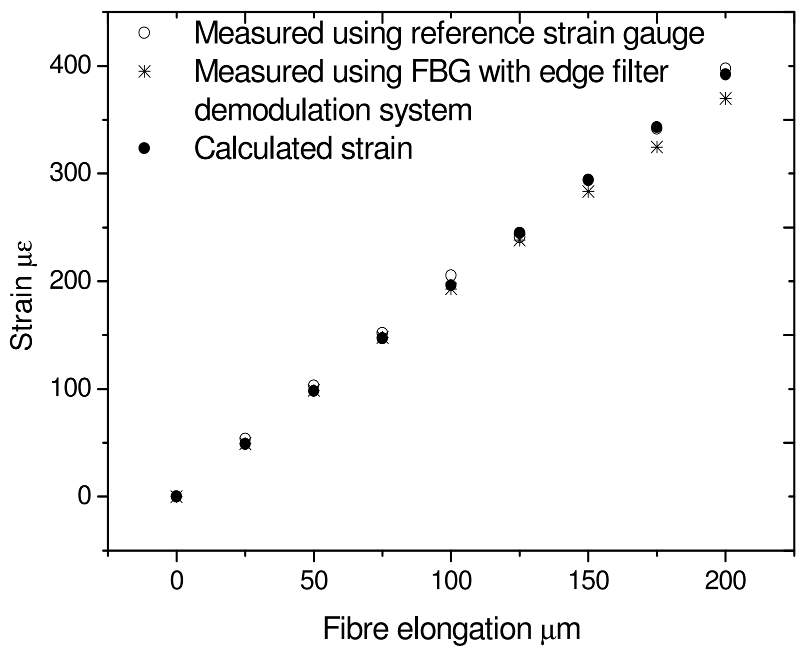

Calculated Strain
Strain measured using method a
Strain measured using method b
Strain με
Fibre eleongation μm
1200
1000
800
600
400
200
0
-200
0
50
100
150
200
250

Figure 5



Measured using reference strain gauge
Measured using FBG with edge filter demodulation system
Calculated strain
400
300
200
100
0
Strain με
0
50
100
150
200
Fibre elongation μm