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***Ahmadullah Shakir**[1]**, Abdul Nahid Rahmahni**[2]**,**
T. M. Bulanova[3]**, K. A. Kassymova**[3]**, N. T. Isaeva**[3]

[1]Afghanistan Urozgan university
[2]Afghanistan Wardak University
[3]Al-Farabi Kazakh National University
*e-mail: Shakir07848@gmail.com

DISCRIMINATION OF TEMPERATURE AND STRAIN INTERFERENCE IN FBG SENSORS USING TAPERED OPTICAL FIBER SENSOR

The optical fiber industry has progressed a lot in recent years. Earlier, they were used as a bed to carry light and image for medical applications, especially in endoscopy. In the mid-1960s, calls were widely used to transmit information. So far, optical fiber technology has been a worthy subject for research. Low loss rate, high bandwidth, electromagnetic reliability, small size, light weight, safety, relatively cheap price, low need for reconstruction and maintenance are the reasons for the attractiveness of optical fibers. In recent years, optical sensors, including FBG, are widely used in the field. Different methods have been used. Among these applications, we can refer to imaging in the fields of civil engineering, aerospace, marine sciences, oil and gas, composites and smart structures. Fiber Bragg Grating (FBG) sensors have found more usages in the industry to diagnose the safety of mechanical structures due to their high sensitivity, non-exposure to the electromagnetic field, linearity, and lightness. A limitation of the application of FBG sensors is the Inability to distinguish the effects of temperature and strain in the simultaneous measurement. For this purpose, we must somehow discriminate the effect of temperature from the strain. In this Article, by designing a tapered fiber-FBG composite sensor we have provided a solution for this problem. Studies performed on the designed composite sensor show that no sensitivity interference will occur in the sensor. In the composite sensor, a tapered fiber optic sensor with a temperature sensitivity of $-932.8\frac{pm}{^{\circ}C}$ *and a FBG sensor with the temperature and strain sensitivity of* $9.89\frac{pm}{^{\circ}C}$ *and,* $0.92\frac{pm}{\mu\varepsilon}$*, respectively, are used.*

Keywords: Tapered fiber, Temperature sensor, FBG sensor, Strain health monitor, Structural health monitor, Interferences.

Introduction

There are different types of optical fiber sensors, of which the thinned optical fiber sensor is one of the most important. In standard optical fiber, the intensity of the wave field on the outer surface is almost zero. To make the optical fiber sensitive to the external environment, it is thinned. By tapering the optical fiber due to the reduction of the diameter of the optical fiber and the increase of the numerical aperture, the amount of penetration depth and the intensity of the attenuation wave field can be significantly increased. [1]

This causes the output to show significant sensitivity to changes in the refractive index of the surrounding environment. Different parts of tapered optical fiber are shown in figure [1].

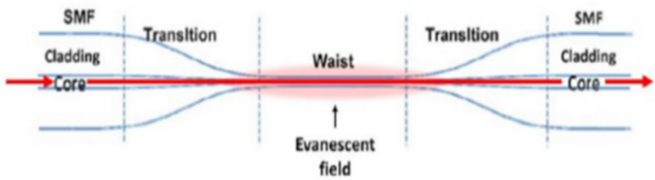


figure – 1 Schematic of tapered optical fiber and its different regions. [3]

The performance of a tapered fiber optic-based temperature sensor relies on a sensitive laminated coating (absorber layer) on the surface of the optical fiber. In this situation, when the temperature of the surrounding environment changes, the physical and chemical properties of the tapered fiber change and these changes change the properties of the light inside the fiber. Changes in the properties of the light beam inside the optical fiber include changes in the intensity, wavelength, or phase of the transmitted light; Therefore, by measuring the parameters of the transmitted light, the temperature value can be calculated. (Figure 2)

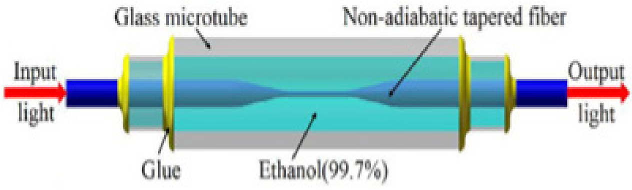


Figure 2 – Schematic diagram of temperature sensor based on thinned optical fiber [4].

Another type of fiber optic sensor are Fiber Bragg Grating sensors. With the discovery of optical sensitivity in optical fibers, it became possible to make optical fiber Bragg Gratings. These gratings simply consist of periodic modulation of the refractive index inside the fiber optic core. Grid-like structures are very important in waveguide optics. Surface-enhanced lattice structures are used in flat waveguide optics for light refinement and coupling [5].

Optical fiber Bragg gratings have been considered as a good sensor for measuring dynamic and static fields such as temperature and strain. One of the most important advantages of sensors made using optical fiber Bragg gratings is its wavelength coding nature. This feature makes the Bragg grating sensors act as a self-reference, independent of the fluctuations of the light level and insensitive to changes in the light intensity of the source and losses caused by the connectors. Due to the low substitution loss and narrow bandwidth reflection wavelength, they can be easily wavelength multiplexed along a single-mode optical fiber [5].

Interferences of the refractive index lead to the reflection of light (propagated along the optical fiber) in a very small range of wavelengths, which is called the reflection wavelength of the Bragg grating or (Figure 3). In addition to the periodicity of the Bragg grating, the reflected Bragg wavelength is dependent on temperature, strain, and other environmental factors, and by applying the smallest change in the said factors, we will have a shift in the reflected wavelength [6].

The intensified wavelength is reflected towards the source and the rest of the wavelengths pass through the part without change or attenuation. The reflection wavelength of an optical fiber Bragg grating is given as follows:

$$\lambda_B = 2n_{eff}\,\Lambda$$

where λ_B, n_{eff} and Λ are the Bragg wavelength (reflection wavelength), effective refractive index and grating period, respectively.

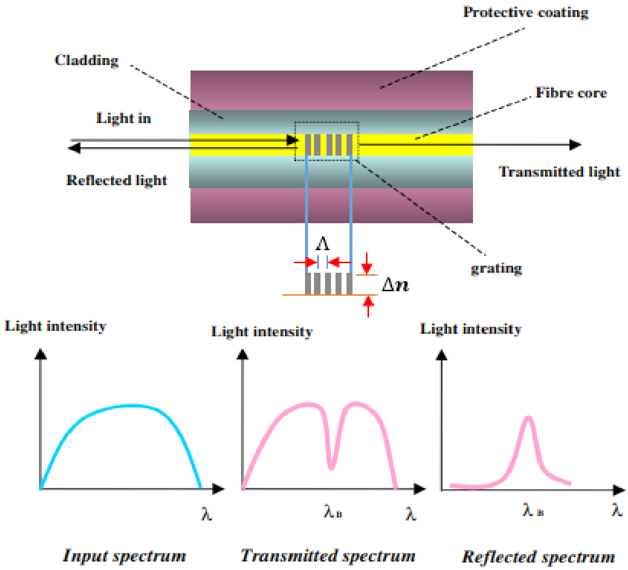


Figure 3 – The general structure of optical fiber Bragg grating [7]

Methods and Materials

In this research, in order to Discrimination the interference of temperature and strain in FBG sensors, a combined sensor design of tapered optical fiber (sensitive to temperature) and fiber optic Bragg grating sensor (sensitive to temperature and strain) was used to measure temperature and strain simultaneously and to separate We act on the effect of temperature and strain. By using the relationships between wavelength changes with strain and temperature, as well as measuring the amount of wavelength changed by each of the tapered optical fiber and the optical fiber Bragg grating, it is possible to determine the temperature and strain at the target point. To illustrate the proposed central idea, we use the experimental results of two types of sensors made by other groups. In reference [4]

Temperature sensor are based on tapered fiber has been tested. Temperature changes from 24°C to 38 °C are considered with a step of 2 °C. The wavelength range is from 1520 nm to 1620 nm, the waist diameter of the tapered area is about 8 micrometers and its length is about 20 mm. Also, the refractive index of 1.36 is considered. The value of the wavelength decreases almost linearly with increasing temperature, and the temperature sensitivity of -932.8 pm/°C has been obtained [4].

The diagram of temperature relationship with wavelength changes for the temperature sensor based on non- adiabatic tapered optical fiber is given in figure [4].

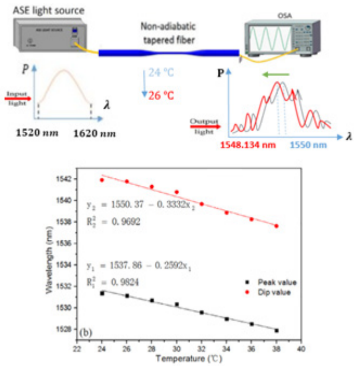


Figure 4 – (a) Schematic diagram of tapered optical fiber-based temperature sensor arrangement (b) Wavelength change in thinned optical fiber-based sensor due to temperature changes [4].

For the Bragg grating sensor, we use the laboratory results of reference [11]. The Bragg wavelength is 1530 nm, the effective refractive index is 1.444, and the temperature and strain sensitivity are $\frac{\Delta\lambda_B}{\Delta T} = 9.89\, {}^{pm}/_{^\circ C}$ and $\frac{\Delta\lambda_B}{\Delta\varepsilon} = 0.92\, {}^{pm}/_{\mu\varepsilon}$ respectively,

The temperature around the optical fiber Bragg grating was changed from 20°C to 80°C with a step of 20°C and the position of the reflection peak was measured. Wavelength changes in terms of temperature changes for the fiber Bragg grating are plotted in (Figure 5).

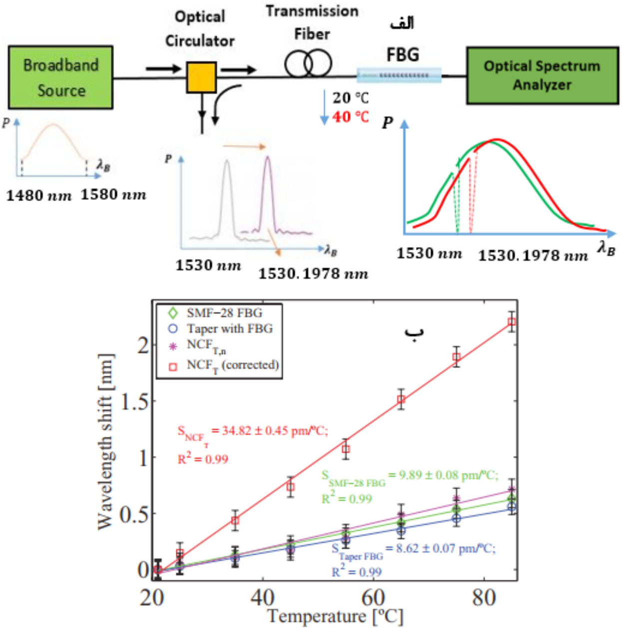


Figure 5 – (a) Schematic diagram of Bragg grating sensor arrangement to measure temperature change (b) Change in wavelength at the peak of the reflection spectrum of FBG due to temperature changes [11].

To measure the strain, the amount of strain has been changed from zero to 1500 microstrain with a step of 100 microstrain [11].

Wavelength changes in terms of strain changes for optical fiber Bragg grating are plotted in Figure (6).

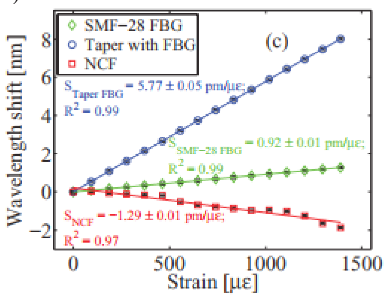
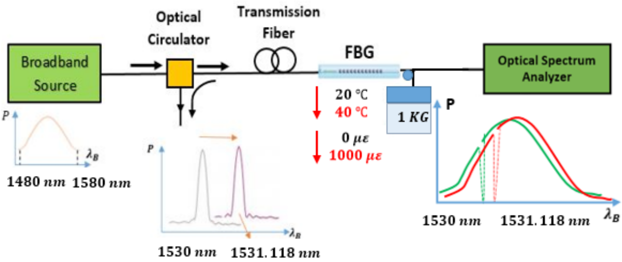


Figure 6 (a) Schematic diagram of Bragg grating sensor arrangement for strain change (b) Wavelength change in FBG due to strain change [11].

Now, we investigate the optical fiber Bragg grating sensor under the simultaneous influence of temperature and strain. This issue is shown schematically in (Figure 7).



(Figure 7) Schematic diagram of Bragg grating sensor arrangement due to simultaneous change of temperature and strain.

As it is clear in(Figure 7) using the FBG sensor to measure temperature and strain simultaneously will cause sensitivity interference; And we cannot measure strain and temperature at the same time using this sensor. In order to eliminate the interference of temperature and strain, we investigate the design of combined sensor of taperned optical fiber and FBG to measure temperature and strain simultaneously. The proposed sensor and the expected shift in the spectrum are schematically drawn in (Figure 8).

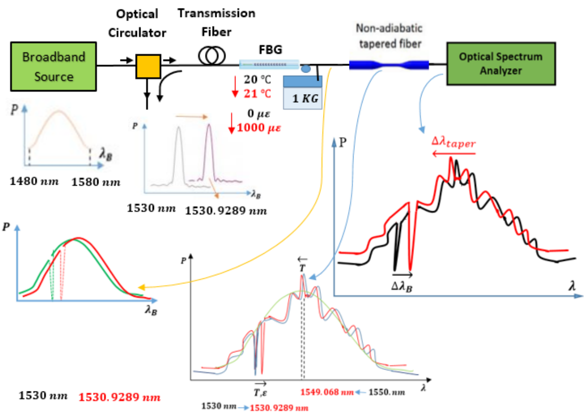


Figure 8 – Schematic diagram of tapered optical fiber and FBG composite sensor arrangement due to temperature and strain changes.

Results and discussion

The temperature sensitivity of optical fiber Bragg gratings is calculated by the following equation. [5]

$$\frac{\Delta\lambda_B}{\lambda_B} = (\alpha + \xi) \cdot \Delta T \quad (1)$$

Also, the axial strain sensitivity of an optical fiber Bragg grating is obtained by the following equation [12]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - P_e)\varepsilon_z \quad (2)$$

By combining equation (1) and (2), the overall sensitivity to temperature and strain is obtained.

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - P_e) \cdot \varepsilon_z + (\alpha + \xi) \cdot \Delta T \quad (3)$$

Equation (3) shows that the displacement of the Bragg grating is caused by two factors, strain and temperature. In order to detect that which factor the displacement is related to, a combined tapered optical fiber and FBG sensor can be used. The temperature-specific thinned fiber optic sensor and the FBG sensor examine both factors, which are obtained by comparing the temperature response of the thinned fiber sensors and the Bragg grating sensor and finally subtracting the result of both sensors from each other, the amount of strain changes.

We rewrite equation (3) as follows:

$$\Delta\lambda_B = K_{\varepsilon B} \times \Delta\varepsilon + K_{TB} \times \Delta T \quad (4)$$

Also, for the thinned fiber optic sensor which is sensitive to temperature we have:

$$\Delta\lambda_{taper} = K_{T\,taper} \times \Delta T \quad (5)$$

The values of $\Delta\lambda_B$ and $\Delta\lambda_{taper}$ can be seen in Figure (8), which can be determined in the laboratory. Now we perform an example of calculations for the proposed sensor. For example, let's suppose that in the laboratory we have measured the wavelength changes for the thinned optical fiber Δ and the Bragg wavelength changes separately and we want to determine the temperature and strain values. For example, let's suppose that in the laboratory we have measured the wavelength changes for the thinned optical fiber $\Delta\lambda_{taper}$ and the Bragg wavelength changes $\Delta\lambda_B$ separately and we want to determine the temperature and strain value. Assume that the values obtained for the wavelength change in the laboratory method for the thinned optical fiber sensor and FBG are $\Delta\acute{\lambda}_{taper} = -0.823\ nm$ and $\Delta\acute{\lambda}_B = 0.751\ nm$, respectively. Now we want to obtain the temperature and strain ($\Delta\acute{T}\ and\ \Delta\acute{\varepsilon}$) using these values.

$$\Delta\acute{T} = \frac{\Delta\acute{\lambda}_{taper}}{K_{T\ taper}} \Longrightarrow \Delta\acute{T} = \frac{-0.823\ nm}{-0.9328^{nm}/_{\circ C}} = 0.883\ ^\circ C$$

$$\Delta\acute{\varepsilon} = \frac{\Delta\acute{\lambda}_B - K_{TB} \times \Delta\acute{T}}{K_{\varepsilon B}} \Longrightarrow$$

$$\Delta\acute{\varepsilon} = \frac{0.751\ nm - 0.00989^{\ nm}/_{\circ C} \times 0.858\ ^\circ C}{0.00092^{\ nm}/_{\mu\varepsilon}} = 807\ \mu\varepsilon$$

This shows that by using the adiabatic thinned optical fiber sensor and FBG in a combined form, the sensitivity interference will not be created in the said sensor, and strain and temperature can be measured simultaneously at any desired point. By using the relationship between wavelength changes with strain and temperature, as well as measuring the value of the changed wavelength by thinned optical fiber and optical fiber Bragg grating, it is possible to use the value of temperature and strain at any desired point. According to the measurements made in the references used in this article [4, 11], the sensitivity for the said combined sensor for temperature and strain was obtained $0.882\ ^{pm}/_{\circ C}$ and $807\ ^{pm}/_{\mu\varepsilon}$ respectively.

Conclusion

The limitation in using optical fiber Bragg grating sensors is that the response of the sensor to measure temperature and strain simultaneously can cause errors in strain measurement in different structures. For this purpose, we have to somehow separate the temperature effect from the strain effect, and various methods have been proposed for this task. In this paper, the design of thinned optical fiber hybrid sensor (sensitive to temperature) and optical fiber Bragg grating sensor (sensitive to temperature and strain) was done to separate the effect of temperature and strain. Investigations conducted on the designed combined sensor showed that sensitivity interference will not occur in the said combined sensor. According to the sensors used as examples in this paper, the sensitivity for the combined sensor was obtained for temperature, $0.882\ ^{pm}/_{\circ C}$ and for strain,$807\ ^{pm}/_{\mu\varepsilon}$.

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Ахмадулла Шакир[1], Абдул Нахид Рахмахни[2], Т.М. Буланова[3], Қ. А. Қасымова[3], Н. Т. Исаева[3]
[1]Ауғанстан Урозган университеті, Ауғанстан;
[2]Ауғанстан Вардак университеті, Ауғанстан;
[3]Әл-Фараби атындағы Қазақ ұлттық университеті,
Қазақстан Республикасы, Алматы қ.
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FBG ДАТЧИКТЕРІНДЕГІ КОНУС ТӘРІЗДІ ТАЛШЫҚ ДАТЧИКТЕРІН ПАЙДАЛАНҒАНДАҒЫ ТЕМПЕРАТУРА МЕН ДЕФОРМАЦИЯ КЕДЕРГІЛЕРІНІҢ ДИСКРИМИНАЦИЯСЫ

Соңғы жылдары оптикалық талшықты индустрия айтарлықтай дамыды. Бұрын олар медициналық қолдану үшін, әсіресе эндоскопияда жарық пен кескінді тасымалдау үшін төсек ретінде пайдаланылды. 1960 жылдардың ортасында қоңыраулар ақпаратты беру үшін кеңінен қолданылды. Осы уақытқа дейін талшықты оптикалық технология зерттеуге лайықты пән болды. Төмен жоғалту жылдамдығы, жоғары өткізу қабілеттілігі, электромагниттік сенімділік, шағын өлшемдер, жеңіл салмақ, қауіпсіздік, салыстырмалы түрде арзан баға, қайта құру және техникалық қызмет көрсетудің төмен қажеттілігі оптикалық талшықтардың тартымдылығының себептері болып табылады. Соңғы жылдары оптикалық сенсорлар, соның ішінде FBG, өрісте кеңінен қолданылады. Әртүрлі әдістер қолданылды. Осы қолданбалардың ішінде біз азаматтық құрылыс, аэрогарыш, теңіз ғылымдары, мұнай және газ, композиттер және смарт құрылымдар салаларындағы бейнелеуге сілтеме жасай аламыз. Fiber Bragg Grating (FBG) сенсорлары жоғары сезімталдыққа, электромагниттік өріске әсер етпеуге, сызықтылыққа және жеңілдікке байланысты механикалық құрылымдардың қауіпсіздігін диагностикалау үшін салада көбірек қолданыс тапты. FBG сенсорларын қолданудағы шектеулер бір мезгілде өлшеу кезінде температура мен деформацияның әсерін ажырата алмау болып табылады. Бұл үшін температураның әсерін штаммнан қандай да бір түрде ажырату керек. Осы мақалада конустық талшықты-FBG композиттік сенсорын жобалау арқылы біз бұл мәселенің шешімін ұсындық. Жасалған композиттік сенсорда жүргізілген зерттеулер сенсорда сезімталдық кедергісі болмайтынын көрсетеді. Композиттік сенсорда -932,8 pm/℃ *температура сезімталдығы* *бар конустық талшықты-оптикалық сенсор және сәйкесінше 9,89 pm/°C және 0,92 pm/με температура мен деформация сезімталдығы бар FBG сенсоры пайдаланылады.*

Кілтті сөздер: конустық талшық, температура сенсоры, FBG сенсоры, деформация мониторингі, құрылымдық денсаулық мониторингі, интерференция.

Ахмадулла Шакир[1], Абдул Нахид Рахмахни[2], Т.М. Буланова[3], Қ. А. Қасымова[3], Н. Т. Исаева[3]
[1]Афганистан Университет Урозган, Афганистан;
[2]Афганистан Университет Вардак, Афганистан;
[3]Казахский национальный университет имени аль-Фараби, Республика Казахстан, г. Алматы.
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ДИСКРИМИНАЦИЯ ПОМЕХ ТЕМПЕРАТУРЫ И ДЕФОРМАЦИИ В ДАТЧИКАХ ВБР С ИСПОЛЬЗОВАНИЕМ КОНИЧЕСКОГО ВОЛОКОННОГО ДАТЧИКА

За последние годы отрасль оптического волокна значительно продвинулась вперед. Ранее они использовались в качестве кровати для переноса света и изображения в медицинских целях, особенно в эндоскопии. В середине 1960-х звонки широко использовались для передачи информации. До сих пор технология оптического волокна была достойным предметом для исследований. Низкий уровень потерь, широкая полоса пропускания, электромагнитная надежность, небольшой размер, малый вес, безопасность, относительно низкая цена, низкая потребность в реконструкции и обслуживании - вот причины привлекательности оптических волокон. В последние годы в полевых условиях широко используются оптические датчики, в том числе ВБР. Использовались разные методы. Среди этих приложений мы можем назвать визуализацию в области гражданского строительства, аэрокосмической промышленности, морских наук, нефти и газа, композитов и интеллектуальных конструкций. Датчики на волоконной брэгговской решетке (ВБР) нашли более широкое применение в промышленности для диагностики безопасности механических конструкций благодаря их высокой чувствительности, неподверженности электромагнитному полю, линейности и легкости. Ограничением применения датчиков ВБР является невозможность различить влияние температуры и *деформации при одновременном измерении. Для этого нужно как-то отделить влияние температуры от деформации. В этой статье мы предложили решение этой проблемы, разработав конический датчик из композитного волокна и ВБР. Исследования, проведенные на разработанном композитном датчике, показывают, что в датчике не будет возникать помех в чувствительности. В составном датчике используются конический волоконно-оптический датчик с температурной чувствительностью -932,8 пм/℃ и датчик ВБР с температурной и тензочувствительностью 9,89 пм/℃ и 0,92 пм/мкε соответственно.*

Ключевые слова: Коническое волокно, Датчик температуры, Датчик ВБР, Монитор состояния деформации, Монитор состояния конструкции, интерференция.

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«Toraighyrov University» баспасынан басылып шығарылған
«Торайғыров университеті» КЕ АҚ
140008, Павлодар қ., Ломов к., 64, 137 каб.

«Toraighyrov University» баспасы
«Торайғыров университеті» КЕ АҚ
140008, Павлодар қ., Ломов к., 64, 137 каб.
+7(718)267-36-69

e-mail: kereku@tou.edu.kz
www.vestnik.tou.edu.kz
https://vestnik-pm.tou.edu.kz/