Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 5, No. 12, December, 2019

Selection of the Optimal FBG Length for Use in Stress-Strain State Diagnostic Systems

Viktor M. Vikulov [a*], Aleksandr V. Todorov [a], Alexey V. Faustov [b], Nikolay L. Lvov [b]

[a] *Scientific and Innovation Center, Institute for the Development of Research, Development and Technology Transfer, Moscow, Russia.*

[b] *Ph.D., Scientific and Innovation Center, Institute for the Development of Research, Development and Technology Transfer, Moscow, Russia.*

Received 27 August 2019; Accepted 16 November 2019

Abstract

The article discusses fiber-optic sensors (FOS) based on the Bragg gratings for measuring systems for diagnostics of stress-strain state. Currently, such diagnostic systems are widely used in construction, industry and civil engineering. The physical principle of deformation diagnostics using FOS. The issues of mounting the sensor on the measured area (detail) are separately discussed. The principle of processing the hardware and software of sensors based on Bragg gratings is described. Research method - bench experiments that were carried out on an equal-deformation beam in order to evaluate the change in the width of the reflected FOS peak at different lengths recorded by the Bragg gratings in order to determine the optimal one. The change in the spectrum of the reflected peak under various deforming influences was monitored. Based on the results obtained, recommendations are made on the use of gratings of various lengths in the diagnostic systems for the stress-strain state of parts and assemblies for civil engineering tasks.

Keywords: Bragg Grating; FBG; FOS; Deformation; Spectrum; Optical Signal.

1. Introduction

Currently, sensors on fiber Bragg gratings (FBG) are widely used to monitor various external influences on the structures of buildings and structures, aircraft structures, etc. [1]. The principle of operation of the FBG is based on the back reflection of the light passing through it at the Bragg wavelength, which depends on the period of the recorded lattice and the effective refractive index [2-4]. Both of these parameters are linearly dependent on changes in temperature and strain that affect the fiber. Tracking in the spectral region of the Bragg wavelength data of the lattice makes it possible to implement sensors of external influences such as temperature and strain gauges [5]. FBG is schematically represented in Figure 1.

Measurement of deformations and temperature at critical points of various structures, both building and aviation, is an important element in monitoring their condition [6, 7]. The use of sensors based on FBG in this case has a number of advantages, such as:

- Small dimensions;
- Lack of sensitivity to electromagnetic interference;
- High resistance to aggressive environments;
- High sensitivity.

* Corresponding author: v_vikulov@nicirt.ru

http://dx.doi.org/10.28991/cej-2019-03091442

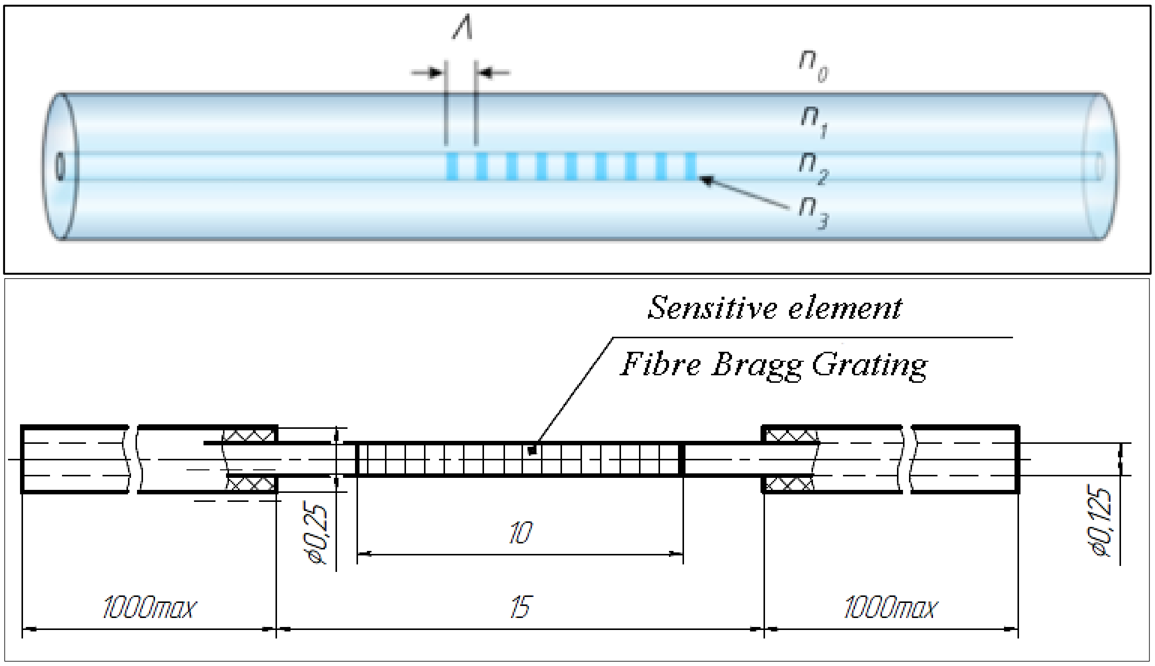

Figure 1. Functional diagram

To develop a measurement system based on FBG, it is necessary to analyze the deviations of the parameters of various sensor manufacturers for changes in the reflected peak parameters, which can affect the accuracy of measuring external influences using FBG. One of the main parameters in this case is the peak width, because when using compact spectrometers such as BaySpec [8] or Ibsen I-MON [8], which have a resolution of 512 points in the spectral range from ~ 30 to ~ 70 nm, to the reflected the Bragg peak is only up to 3-5 points per peak. The purpose of the experiments described below was to determine the optimal FBG parameters for developing systems for measuring the stress-strain state.

This article discusses FBGs of two manufacturers made using the same technology of recording with a phase mask [9-11], in standard germanosilicate fibers of the SMF-28 type, except for fibers with increased mode retention due to a reduced core and a complex refractive index profile. The relevance of this study is due to the large number of publications related to the description of systems for diagnosing the stress-strain state of various parts and assemblies (structures, machines, movable equipment) based on FBG [12, 13].

2. Stand Description

The main objective of the tests is to compare changes in the central wavelength of the reflected signal from different (FBG) with the same deforming effect on the mounting detail of the FBG. The tests were carried out at room temperature and at elevated (+80 ºC).

Types of FBG used in the tests:

- Type 1, Manufacturer No. 1, the length of the recorded lattice is 10 mm, the fiber type is analogue to SMF-28 (designation on the graphs D1530_CH_10).
- Type 2, Manufacturer No. 2, the length of the recorded lattice is 10 mm, the fiber type is analogue to SMF-28 (designation on the graphs D1535_IT_10).
- Type 3, Manufacturer No. 2, the recorded lattice length is 3 mm, the fiber type is analogue to SMF-28 (designation on graphs D1560_IT_03).
- Type 4, Manufacturer No. 2, the recorded lattice length is 3 mm, the type of fiber is fiber with increased mode retention (designation on the graphs D1545_IT_10_TC).

The reflected peaks of FBGs of Type 3 and 4 with a grating length of 3 mm are approximately 2 times wider than the peaks of FBG with a length of 10 mm, which is usually considered a negative factor. However, in the case of low-resolution spectrometers, wider spectra may be advantageous since they will have a larger number of dots per peak. The parameters of the reflected Bragg peak were analyzed at the experimental bench, see Figure 2. The Yokogawa AQ6370 C optical spectral analyzer was used as a spectrometer.

The full functional diagram of the stand is shown in Figure 2.

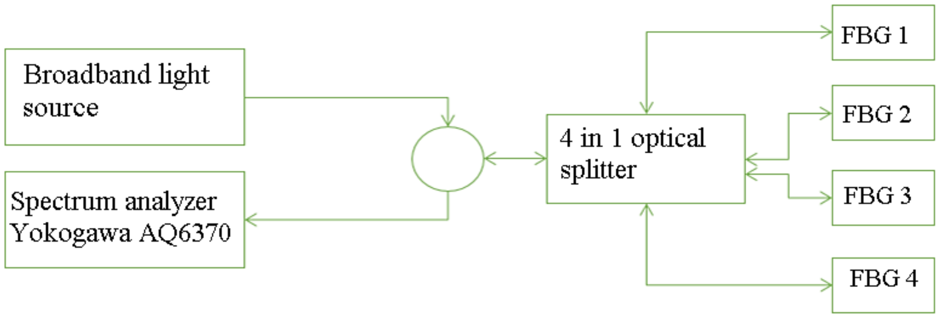

Figure 2. Functional diagram

For measurements, FOS were mounted on the surface of an equal strain plate using Araldite © glue [14]. A view of an equal strain plate with sensors on a load tool with a micrometer screw is shown in Figures 3 and 4, respectively.

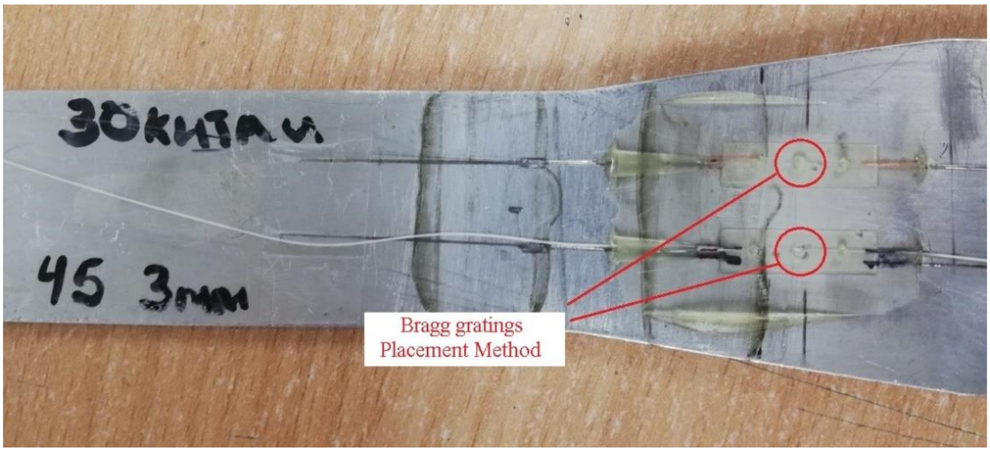

Figure 3. Plate of equal deformations with FOS

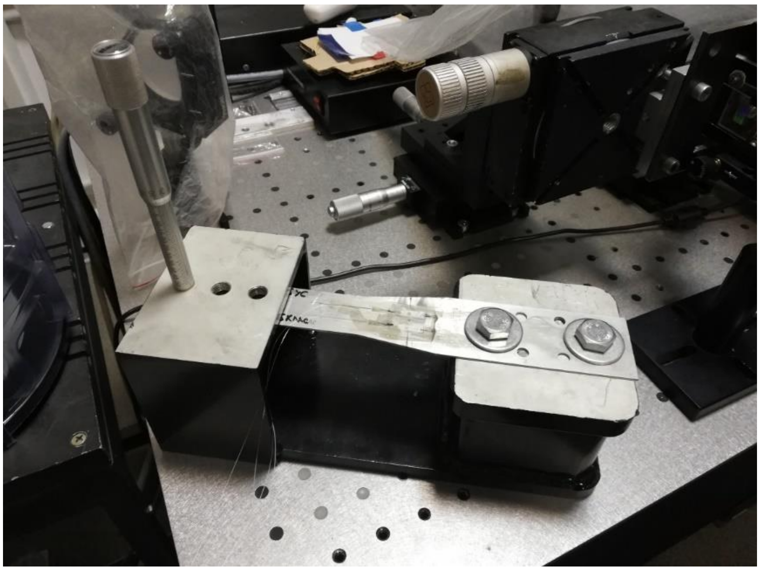

Figure 4. Load equipment with a micrometer screw

3. Experiment Description

After connecting the measuring stand using a micrometer screw, deformation was applied to the beam with a pitch of 2.5 mm; for thermal tests, the step was 5 mm. The data obtained from the spectrum analyzer were entered in the table. Two values were shot:

- Indications of the FBG wavelength at a given bias, i.e. wavelength at the peak of the spectrum of the signal from the FBG.
- The width of the spectrum of the signal from the FBG (at a level of 3 dB from the peak).

For a more accurate comparison, the wavelengths were converted to relative units (normalized) by the formula: $\lambda_t = \frac{\lambda_T - \lambda_0}{\lambda_0}$.

Figure 5 shows an example of the spectrum of the return signal from the FBG.

Figure 5. Spectrum of the return signal from FBG

When the peak position deviated due to an increase in the applied strain, the spectrum width of the reflected Bragg peak was analyzed [15], which directly shows the quality of the return signal.

4. Test Results

Figures 6 to 9 show the dependency graphs for room and elevated temperatures during compression and tension of the plate.

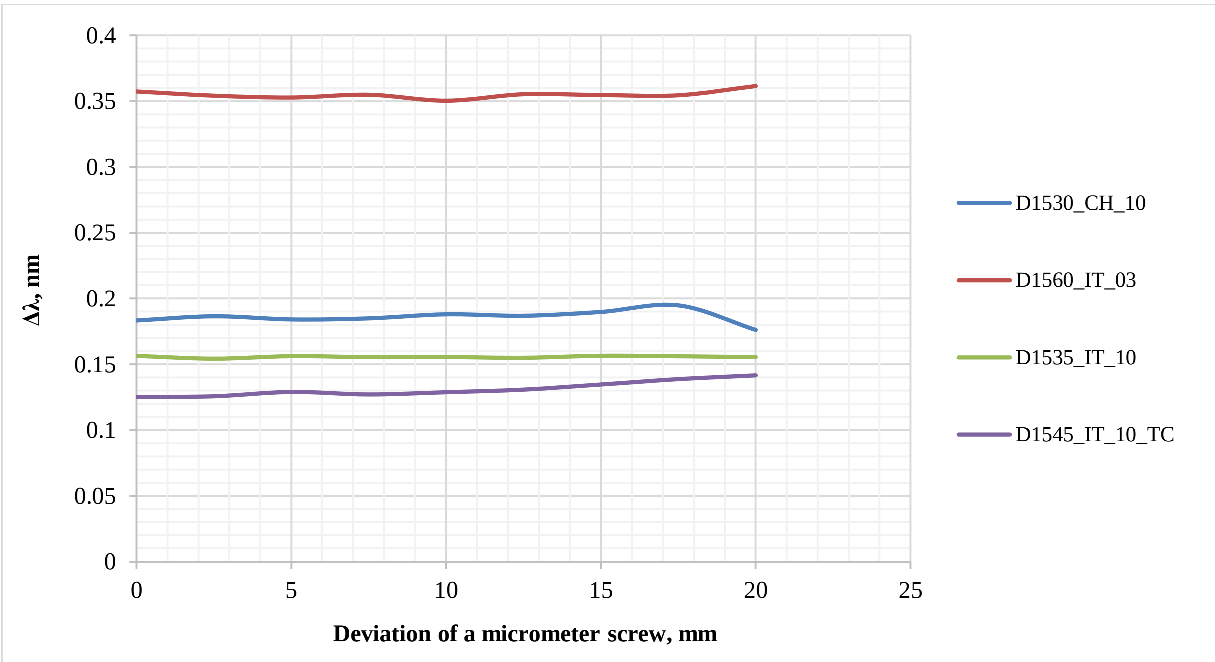

Figure 6. Change in the width of the spectrum of the optical signal with increasing external exposure, compression at a temperature of +25 ° C

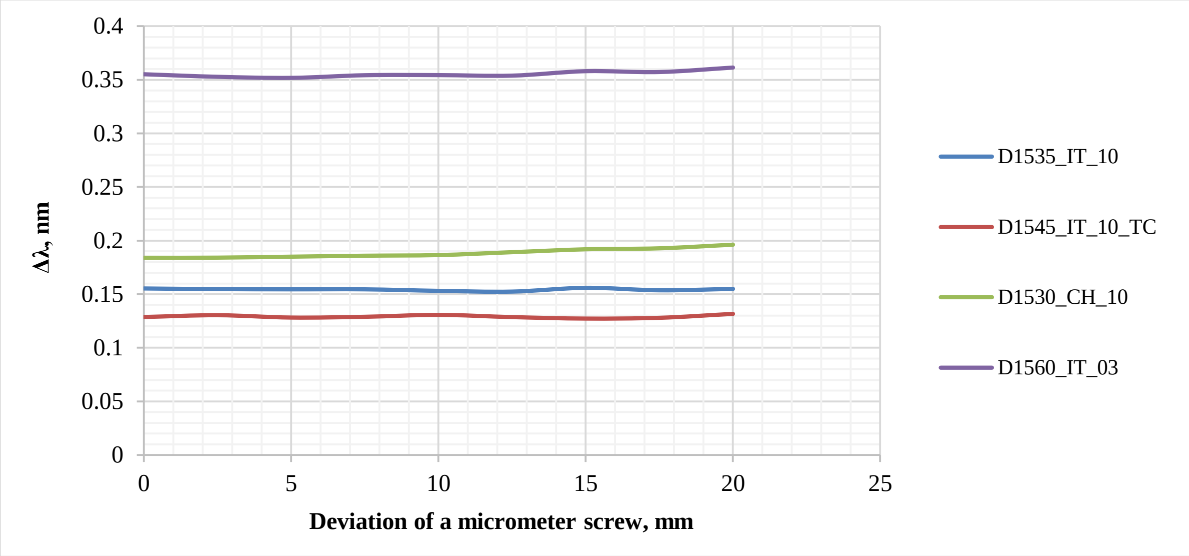

Figure 9. Change in the spectrum width of the optical signal with increasing external exposure, compression at a temperature of +25 ^{0} C

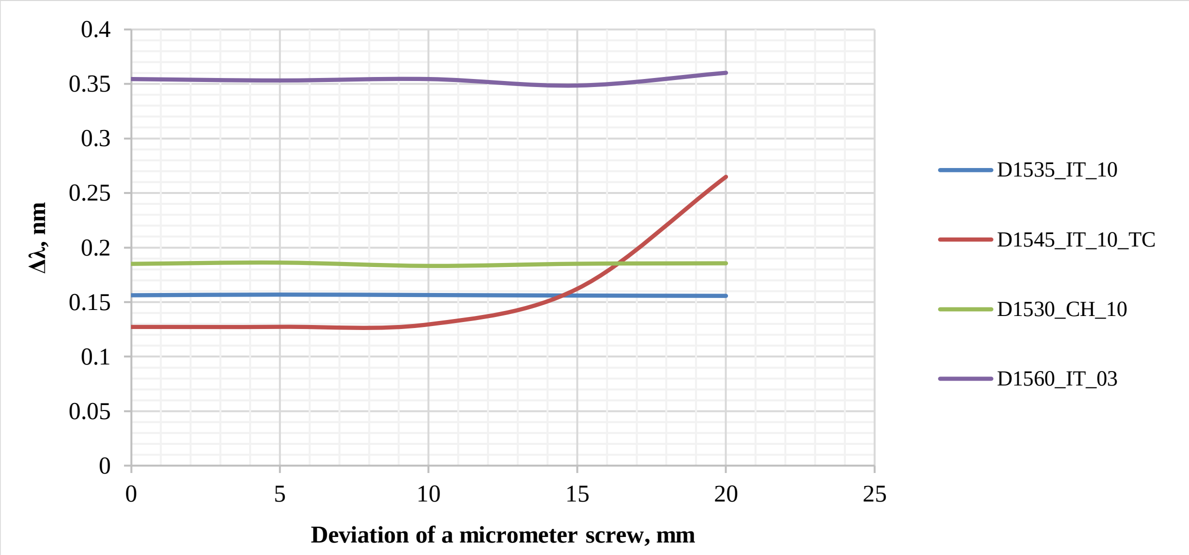

Figure 8. Changing the width of the spectrum of the optical signal during compression. Temperature +80 ^{0} C

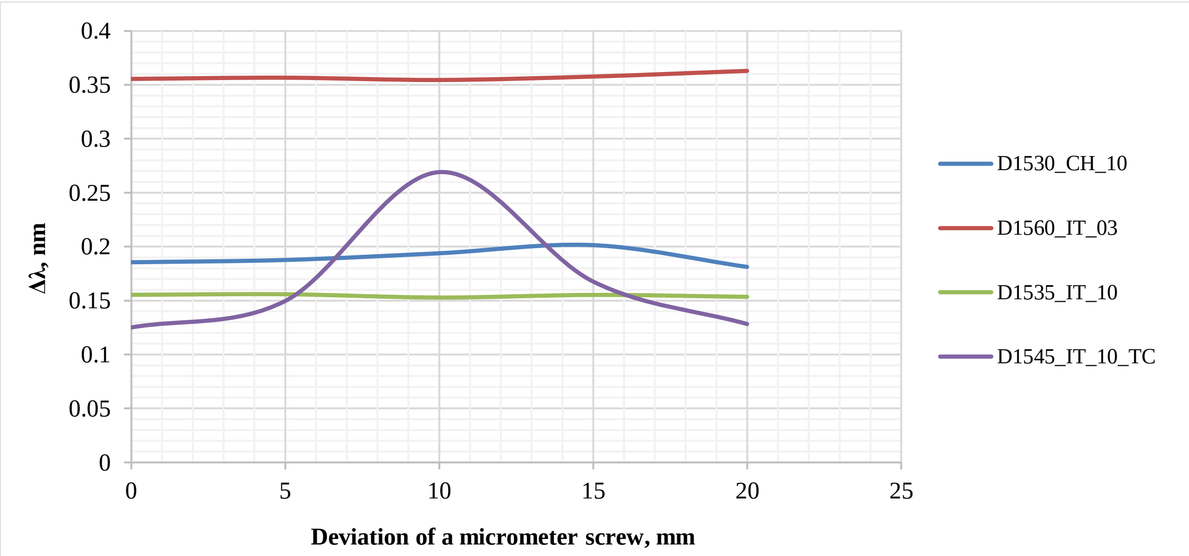

Figure 9. Changing the width of the spectrum of the optical signal in tension. Temperature +80 ^{0} C

5. Practical Findings

As a result of the tests, the following practical conclusions can be drawn:

1. All tested FBGs show equally stable values of the change in deformation under normal conditions (room temperature). However, the spectra of the signals reflected from the FBG undergo significant changes. So, Type 1 and Type 2 sensors indicate the occurrence of side peaks near the main one. The second peaks tend to move in the vicinity of the main peak with an increase in the deforming effect. An example of the appearance of peaks is shown in Figure 10.

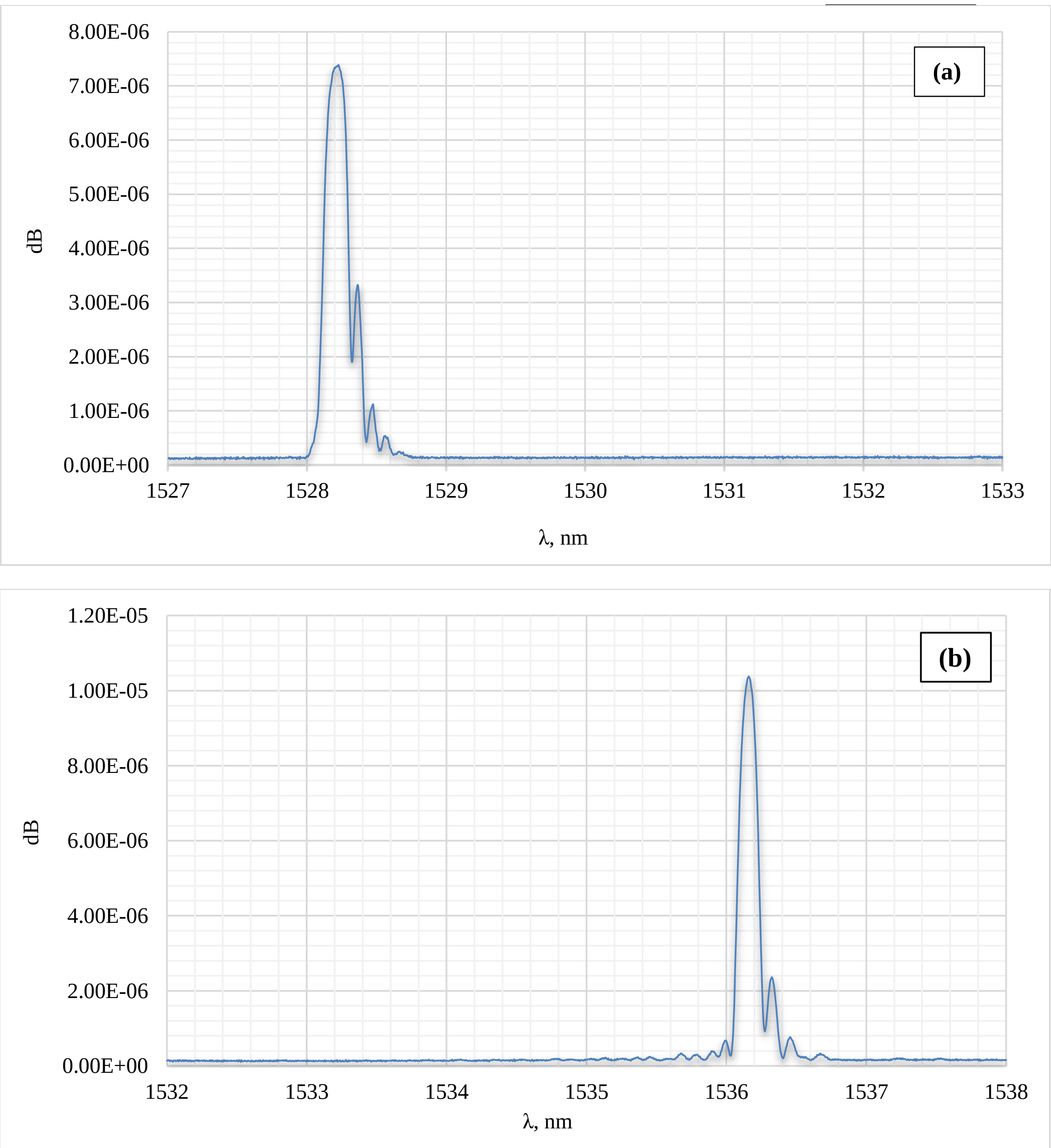

Figure 10. The occurrence of second peaks during deformation on the sensors Type No. 1 (a) and Type No. 2 (b)

With a large number of spectrum points during processing, this problem is not significant, since the peaks are algorithmically distinguishable and can be filtered by setting a threshold intensity value.

In the case of the compact spectrometers described above, in which the resolution is much lower than the laboratory position of the peak, it is often necessary to determine only three points. Thus, the appearance of significant side peaks can lead to an increase in the error in accurately determining the position of the peak.

2. When heated, the deformation characteristics shown by the FBG had significant differences, which can be explained by the thermal expansion of the glue and sensors. The worst characteristics of a decrease in intensity and a departure from the reference type of spectrum were shown by Type No. 4 (Figure 11), which is probably due to the imperfection of recording technology in fibers with a complex shell structure.

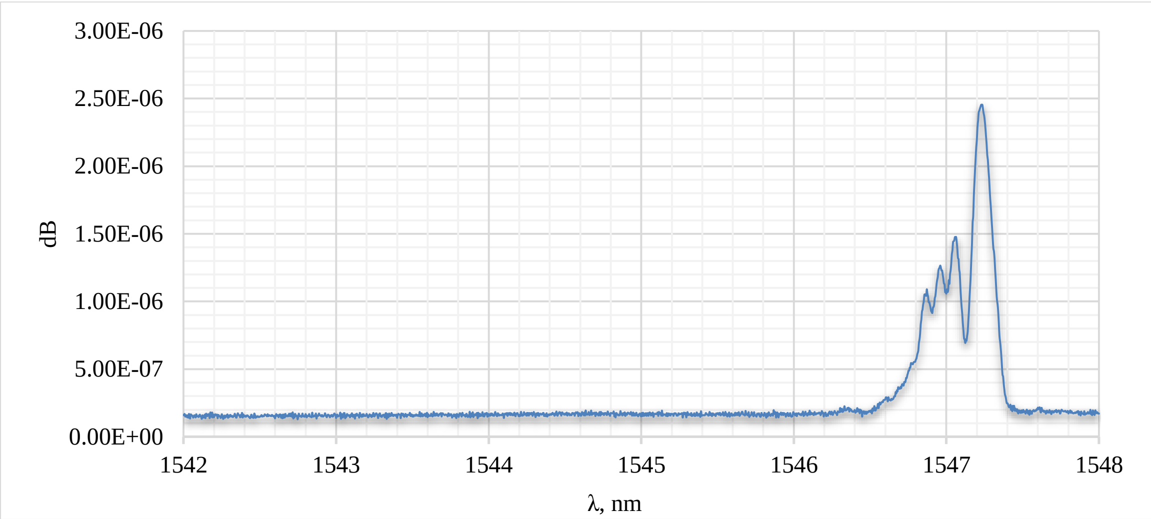

Figure 11. Changes in the shape of the spectrum of FBG Type No. 4

3. A Type 3 sensor, having a length of 3 mm, showed the best spectral characteristics. The spectrum view of this FBG did not change its appearance at all load values and with temperature changes (Figure 12).

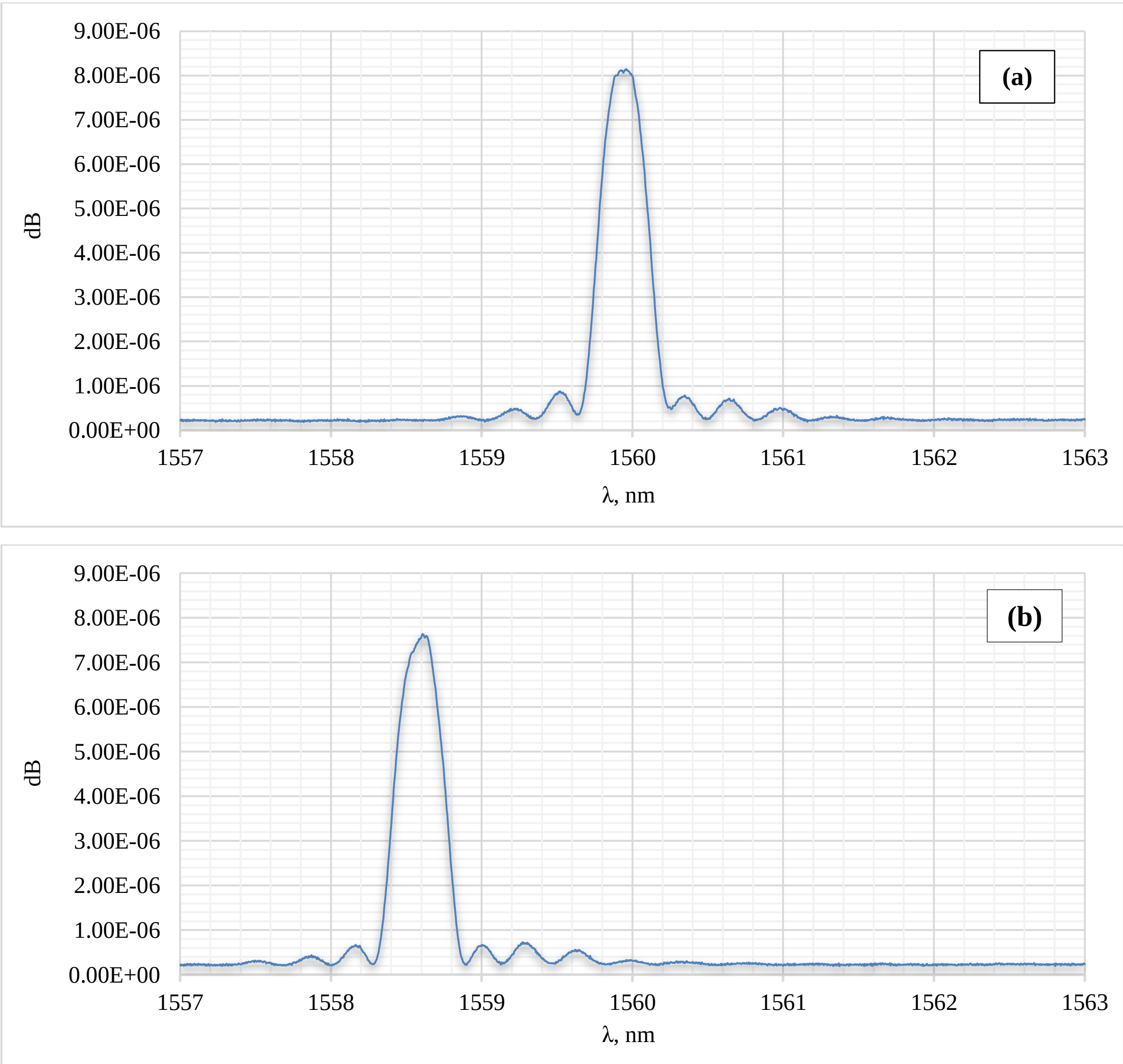

Figure 12. Spectrum of FBG Type No. 3. At room temperature without deformation (a), at + 80 ° C with maximum deformation (b)

This advantage is due to the localization of the sensor on a smaller area, which leads to less susceptibility to mounting errors and possible heterogeneities in the adhesion of glue to the fiber.

6. Conclusion

Based on the results obtained, it can be concluded that for further testing and application in strain-measuring systems based on FBG, it is better to use shorter gratings, since they have the most stable spectral characteristics. In addition, the shorter grating length, leading to broadening of the spectrum, is also an advantage compared to longer gratings with a narrow spectrum when used in measurement systems using compact low-resolution spectrometers. These results will help to significantly improve and stabilize FBG diagnostic systems.

In the future, it makes sense to test the FBG with the shortest possible length (1 mm for ITMO University). This type of FBG can be promising for introduction into composite materials (CM), since the localization of the deformation effect will be minimal. This characteristic is important because of the features of the technology for the production of parts from CM - baking and pressure. With a smaller base of the sensitive part of the FBG, the likelihood of unwanted compression and, as a result, changes in the spectral characteristics of the FOS embedded in the CM decreases.

7. Funding

The authors are grateful to the Russian Ministry of Education and Science for co-financing a project to develop a system for detecting stall phenomena on the rotor blades of a helicopter during flight and monitoring the technical condition of the swashplate (agreement No. 14.579.21.0150, identification number RFMEFI57917X0150), within the framework of which results were obtained that were included in this article.

8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

[1] Othonos, Andreas, Kyriacos Kalli, and Glenn E. Kohnke. “Fiber Bragg Gratings: Fundamentals and Applications in Telecommunications and Sensing.” Physics Today 53, no. 5 (May 2000): 61–62. doi:10.1063/1.883086.

[2] S.V. Vargel, Fiber Bragg gratings. St. Petersburg: ITMO University, 2015. 65 p.

[3] Hisham, H. K., “Fiber Bragg Grating Sensors: Development and Applications. Boca Raton”: CRC Press, (June 19, 2019). doi: 10.1201/9780429275135

[4] Kumar, Ramesh, and Anurag Sharma. “A New Method to Analyze Fiber Bragg Gratings.” Optical Fiber Technology 53 (December 2019): 102017. doi:10.1016/j.yofte.2019.102017.

[5] Yu.V. Gulyaev, S.A. Nikitov, V.T. Potapov, Yu.K. Chamorovsky. Fiber-optic technologies, devices, sensors and systems. Special issue "PHOTON-EXPRESS". (2005), No. 6. pp. 114-127.

[6] Kaplan, N., J. Jasenek, and J. Cervenova. “Simultanous Measurement of Temperature and Strain Based on HiBi FBG Using OFDR.” 2017 11th International Conference on Measurement (May 2017). doi:10.23919/measurement.2017.7983543.

[7] Salo, Jussi, and Ilkka Korhonen. “Calculated Estimate of FBG Sensor’s Suitability for Beam Vibration and Strain Measuring.” Measurement 47 (January 2014): 178–183. doi:10.1016/j.measurement.2013.08.017.

[8] FBG Interrogators; Available online: http:// micronoptics.com/how-do-fbg-sensor-interrogators-work (accessed on 1 May 2019).

[9] S.V. Vargel, A.V. Kulikov, V.A. Aseev, V.S. Brunov, V.G. Kalko, V.A. Arteev. Recording narrow-band fiber Bragg reflectors with a single pulse of an excimer laser using the phase mask method. Scientific and Technical Journal of Information Technologies, Mechanics, and Optics, 2011. No. 5 (75). Pp. 27-30

[10] Habel, Joé, Tommy Boilard, Younès Messaddeq, François Trépanier, and Martin Bernier. “Flexible Phase-Mask Writing Technique of Robust Femtosecond FBG for Distributed Sensing.” Advanced Photonics 2018 (BGPP, IPR, NP, NOMA, Sensors, Networks, SPPCom, SOF) (2018). doi:10.1364/bgppm.2018.bm3a.4.

[11] Zhao, Yujia, Ling Pan, Yang Ouyang, Xiaofeng Xu, Ciming Zhou, Ai Zhou, and Libo Yuan. “Multi-Wavelength FBG Based on Thermal Diffusion and Phase Mask Techniques.” Optics Communications 427 (November 2018): 257–260. doi:10.1016/j.optcom.2018.06.047.

[12] Wang, H. P., P. Xiang, and X. Li. “Theoretical Analysis on Strain Transfer Error of FBG Sensors Attached on Steel Structures Subjected to Fatigue Load.” Strain 52, no. 6 (July 7, 2016): 522–530. doi:10.1111/str.12195.

[13] Takahama, Toshimitsu, Atsushi Yokotani, and Kou Kurosawa. “Development of FBG Strain-Detection System with Narrow Band Filter Using a Scanning FBG.” IEEJ Transactions on Sensors and Micromachines 127, no. 1 (2007): 19–24. doi:10.1541/ieejsmas.127.19.

[14] Gooch, Jan W., ed. Encyclopedic dictionary of polymers. Vol. 1. Springer Science & Business Media, 2010.

[15] Divliansky, Ivan, Marc SeGall, Daniel Ott, and Leonid Glebov. “Chirped Volume Bragg Gratings as Broad Spectrum Focusing or Collimating Elements.” CLEO: 2013 (2013). doi:10.1364/cleo_at.2013.jtu4a.24.