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ҰЙЫМДАСҚАН ҚЫЛМЫСҚА ҚАРСЫ КҮРЕСТІҢ ПЕРСПЕКТИВАЛЫҚ АВТОМАТТАНДЫРЫЛҒАН ЖҮЙЕЛЕРІ ТУРАЛЫ

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Аңдатпа. Осы мақала құқық қорғау органдары ұйымдасқан қылмысқа қарсы күрес үшін пайдаланатын техника мен технологиялар деңгейін арттыру тақырыбына арналған. Атап айтқанда, қылмыстарды анықтаудың, алдын алудың, жолын кесудің және ашудың неғұрлым тиімді әдісі, сондай-ақ дәстүрлі іс жүргізу құралдарымен салыстырғанда ақпарат жинаудың тиімді әдісі ретінде жедел-іздестіру қызметін ішінара автоматтандыру мәселесі айтылды. Жұмыста жедел-іздестіру қызметі туралы жалпы мәліметтер берілді, бақылау сияқты жедел-іздестіру іс-шарасын жүргізудің кезеңдері мен ерекшеліктері талқыланды, адам тудырған оны жүргізу проблемалары ашылды. Белгіленген мәселелерге сүйене отырып, оларды шешуге қабілетті автоматтандырылған жүйелерге арналған жарияланымдарды іздеу және талдау жүргізілді. Осылайша, жұмыста негізгі назар құқық қорғау органдары үшін перспективалы автоматтандырылған жүйелерді әзірлеудегі халықаралық тәжірибені қарастыруға аударылды. Жарияланымдарды талдау негізінде ұйымдасқан қылмысқа қарсы күрестің перспективті автоматтандырылған жүйелерінің үш категориясы бөлінді: жылжымалы нысандарды тану және бақылау бейне жүйелері, көптеген гетерогенді деректерді автоматтандырылған өңдеу жүйелері, дыбыс көздерін тану және локализациялау жүйелері.

Түйінді сөздер: жедел іздестіру қызметі, жедел іздестіру іс-шарасы, бақылау, бағдарламалық жасақтама, өзекті мәселе.

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MATHEMATICAL JUSTIFICATION OF FIBER SENSORS BASED ON FIBER BRAGG GRATINGS

Abstract. Nowadays, the most promising approach is the use of fiber-optic sensors as a key element of the monitoring system. Fiber-optic sensors (FOS) have a number of advantages, the most important of which include immunity to electromagnetic interference, low weight and the possibility of their inclusion in the measured structure. The use of such sensors in the monitoring system will make it possible to simplify the measurement and obtain reliable data, as well as to obtain all new possibilities for measuring various quantities simultaneously.

The most perspective are the sensors based on the Bragg fiber gratings. Bragg fiber gratings have several advantages, for instance, they allow creating the distributed measuring massifs, which contain several sensors. As well, they are insensitive to the optic power source vibrations. Variety of using the fiber sensors based on the Bragg fiber gratings has led to producing the Bragg fiber gratings with different spectral characteristics.

The article herein considers the issues of the Bragg fiber gratings mathematical modeling using the transfer matrix method. Transfer matrix method allows defining the optical components spectral characteristics based on the bound modes theory and description of electromagnetic wave, passing through an optic fiber. In the article there have been analyzed the Bragg fiber gratings in compliance with spectral features, such as transmission and reflectance spectra.

Key words: monitoring, fiber-optic sensors, Bragg fiber gratings, mathematical modeling.

Introduction

Over the past two decades, a significant number of innovative sensor systems based on fiber-optic sensors have been used in the engineering community due to their distinctive advantages, such as small size, light weight, resistance to electromagnetic interference and corrosion, as well as the possibility of embedding. Many monitoring systems based on fiber-optic sensors have been developed for continuous measurement and real-time evaluation of various engineering structures, such as bridges, buildings, tunnels, pipelines, wind turbines, railway infrastructure and geotechnical structures.

Not a few studies and developments have been done on the progress of the use of fiber-optic sensors for monitoring various types of engineering structures. Most often, the use of fiber sensors based on Bragg fiber arrays (FBG) attracts great interest. They are based on the phenomenon of Bragg diffraction on periodic structures in optical fibers [1]. These structures represent a periodic change in the refractive index of the material in which the electromagnetic wave propagates. Thus, control over the propagation of light can be achieved: from spectral and spatial selectivity to changes in the signal propagation velocity and dispersion characteristics of the medium. These phenomena are widely used in the field of creating elements of telecommunication systems, laser sources and high-precision sensors [2-7]. Also, fiber sensors based on FBG are used to monitor the condition of large composite and concrete structures, in the development of structurally integrated fiber-optic sensors for intelligent structures, in the electric power industry, medicine and chemical production.

Nowadays, sensors based on Bragg gratings are actively used in various fields of construction, industry to monitor many key technological parameters, the condition of structural elements and complex engineering structures, practically displacing electrical analogues. Bragg gratings are also key elements of modern fiber lasers.

Despite the active development of this area in science and industry over the past three decades, there are many pressing issues, including the development and application of new principles in fiber sensors, solving key problems that limit the use of sensors based on Bragg gratings in difficult operating conditions, including high temperatures and operation in the presence of high-intensity ionizing radiation. Special attention should be paid to the issues of monitoring systems research.

The Bragg fiber gratings (FBG) is a section, as a rule, of a single-mode fiber fiber, in the core of which a periodic structure is formed, which is a modulation of the

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refractive index along its axis. At the same time, the characteristic modulation period for the gratings of the first, most common, order is half the working wavelength of light in the substance.

The main characteristics of the Bragg fiber gratings: transmission and reflection spectra are shown in Figure 1 on the example of a gratings with a period Λ = 527 nm and a length L = 5 mm. It should be noted that the properties of the gratings are often described by its transmission spectrum on a logarithmic scale, which is convenient for a comparative evaluation of the FBG with a large reflection coefficient. The transmission spectrum of the gratings is represented by a blue curve and corresponds to the left ordinate axis, along which the signal intensity in absolute units (dB) is deposited. The value of the total transmission in the region of -36 dB corresponds to the intensity of the broadband source, with the resolution of the optical spectrum analyzer at 0.06 nm. The red curve shows the corresponding spectral dependence of the reflection coefficient.

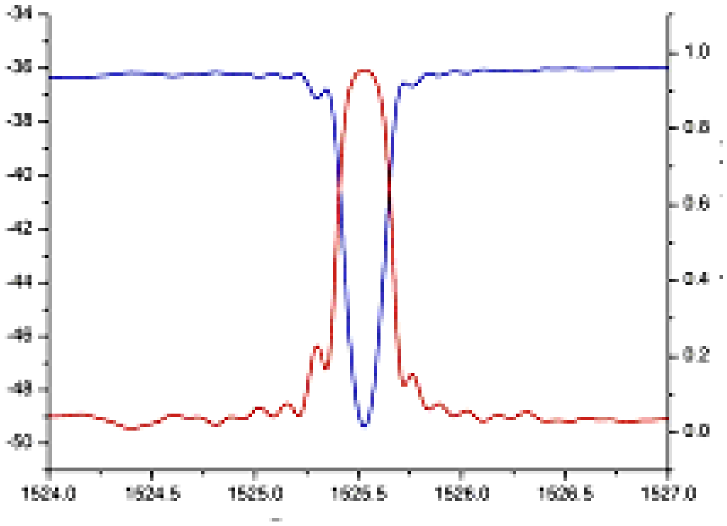

Figure 1 - Transmission and reflection spectrum of the FBG

The structure and principles of FBG can be seen in Figure 2.

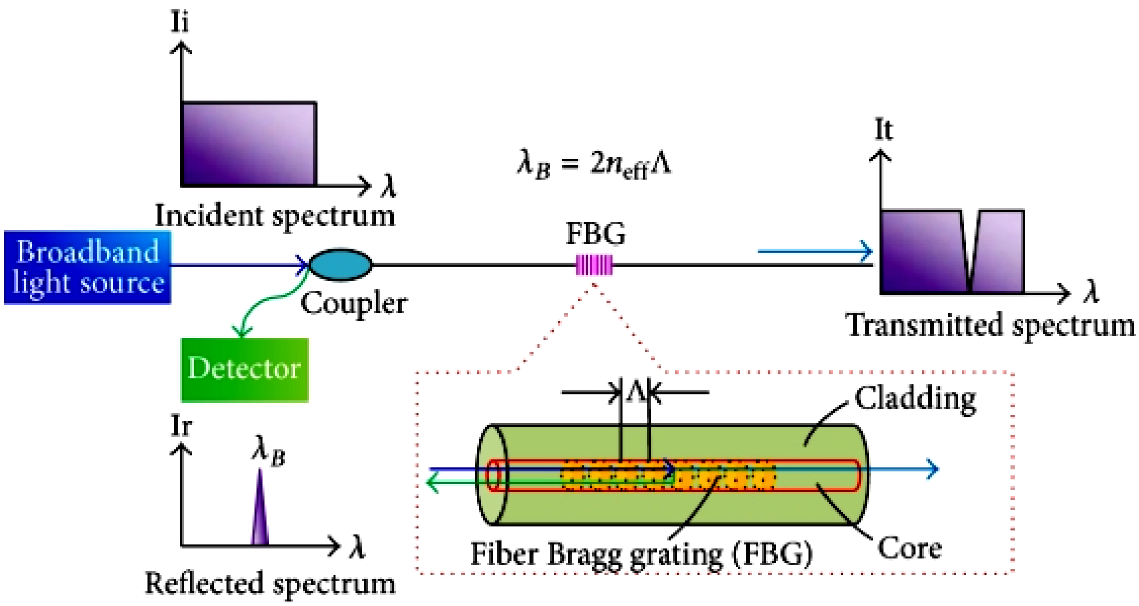

Figure 2 - Principles of operation and wavelength shift of sensors with FBG

Having considered the main advantages and the principle of operation of Bragg fiber gratings, we proceed to the consideration of the mathematical model.

The theory of FBG can be formulated by describing the propagation of modes in an optical fiber. Therefore, this section will first consider the properties of electromagnetic wave propagation in an optical fiber, after which the main provisions of the transfer matrix method (TMM) will be formulated.

The mathematical apparatus used in the transfer matrix method modes is described in detail in many works of researchers. We have taken the existing mathematical expressions as a basis. When describing the problem, one should start with the fundamental expressions linking the electric

One of modeling techniques is the transfer matrix method (TMM) [8], which allows specifying the optic elements spectral characteristics based on the bounded modes theory and matrix describing the electro-magnetic wave, passing through the optic fiber following periods [9].

displacement vector, electric field strength, magnetic vector and flux, induced polarization.

Mathematical model of Bragg gratings.

The parameters of Bragg fiber gratings can be mathematically modeled in several ways. The most commonly used method is the application of coupled mode theory, since it is the most suitable tool for describing the propagation of modes in a waveguide with a slowly varying refractive index along it. The FBG is just this structure. The main idea of the theory of coupled modes is that the electromagnetic field inside a waveguide with inhomogeneities can be represented by a linear combination of field distribution modes without inhomogeneities.

In such approach we suppose, that the grating overall length L is broken down into exactly determined sections N, so that each section, having been created in such a manner with a length Δz= L/N, can be considered as homogeneous. Transmission matrix, describing the i- section will be defined as follows [10]:

$$T_i = \begin{bmatrix} \cosh(\gamma \otimes z) - \frac{\sigma}{\gamma}\sinh(\gamma \otimes z) & -i\frac{k}{\gamma}\sin(\gamma \otimes z) \\ i\frac{k}{\gamma}\sin(\gamma \otimes z) & \cosh(\gamma \otimes z) - \frac{\sigma}{\gamma}\sinh(\gamma \otimes z) \end{bmatrix} \quad (1)$$

For the definition above, it is also assumed, that κ- variable, coupling factor constituent for refraction coefficient contrast ratio v=1, being analyzed wave’s length λ and envisaged apodization function g will be(z):

$$k = \frac{\Pi}{\lambda} \cdot v \cdot \hat{\sigma}_{eff}(z) \quad (2)$$

$$\bar{\delta}_{eff}(z) = \delta_{eff} \cdot g(z) \quad (3)$$

During Bragg grating simulation the variable coupling ratio component value κ depends on the selecting the refraction factor envelope function (2). General coupling coefficient is defined with the equation (4). It is as well known, that λ_B – Bragg wave length, and n_{eff} - effective refraction factor.

$$\hat{\sigma} = \delta + \sigma - \frac{1}{2}\frac{d\phi}{dz} \quad (4)$$

$$\delta = 2\Pi n_{eff}\left(\frac{1}{\lambda} \cdot \frac{1}{\lambda_B}\right) \quad (5)$$

$$\sigma = \frac{2k}{v} \quad (6)$$

Parameter γ for transmission matrix is specified as follows:

$$\gamma = \sqrt{k^2 + \hat{\sigma}^2} \quad (7)$$

Overall grating features can be described as

$$\begin{bmatrix} R_0 \\ S_0 \end{bmatrix} = T \begin{bmatrix} R_N \\ S_N \end{bmatrix} \quad (8)$$

$$T = [T_N]\cdot[T_{N-1}]\cdots[T_3]\cdot[T_2]\cdot[T_1] \quad (9)$$

Values of matrix parameters T might be used for defining characteristics of both reflected (10), and transmitted (11) waves. Further the indexed components Tij indicate the elements values under the i- column and j-line of transmission matrix.

$$R = \frac{T_{21}}{T_{11}} \quad (10)$$

$$S = \frac{1}{T_{11}} \quad (11)$$

Based on the transfer matrix method and using various methods for determining the dispersion dependence of the effective refractive index, it is possible to build an algorithm of commands in the Matlab mathematical package, which allows, among other things, to calculate the reflection spectrum of various types of FBG and Bragg wavelength. The considered mathematical model can be very useful, i.e. it is possible to develop various optical systems using computer tools. The use of computer modeling does not fully reflect all physical and chemical phenomena, but provides parameters close to reality for modeling, comparing and selecting optimal parameters of fiber Bragg gratings.

Using the above, we experimentally examined gratings with different Bragg wavelengths. Namely, apodized Bragg gratings. The gratings used have a Bragg wavelength of 1550 nm with an effective refractive index of 1.447. The simulation results are shown in Figure 3 below

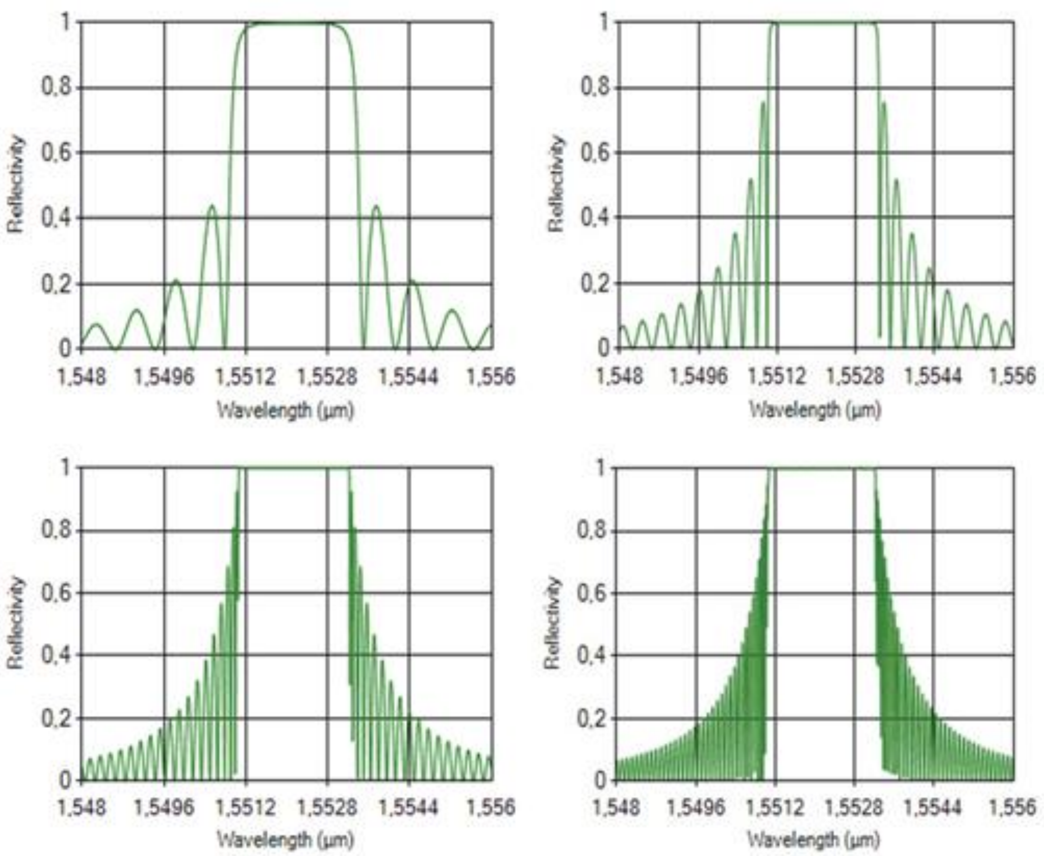

Figure 3 - Transmission spectrum characteristics for different Bragg wavelengths (1 mm, 2 mm, 4 mm, 8 mm)

It is also possible to consider and obtain results for different Bragg wavelengths (1546 nm, 1550 nm). The results of the observations were placed on consecutive graphs, Figure 4.

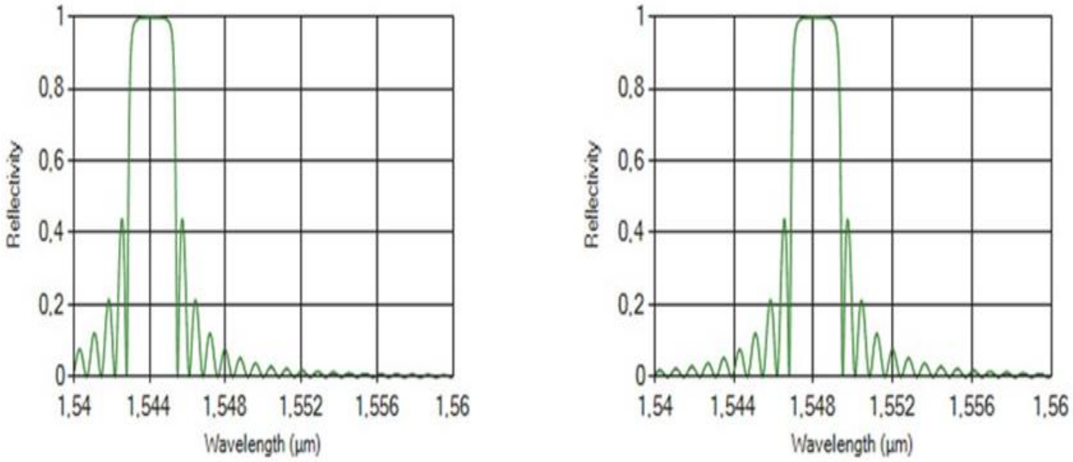

Figure 4 – Transmission spectrum for different Bragg wavelengths (1546 nm, 1550 nm)

The presented features are only a part of the available modeling parameters. However, this topic will be discussed in more detail in a future publication.

Conclusion Nowadays, scientific and technical directions are actively developing related to the creation of small-sized, reliable and economical devices for monitoring the parameters of movement and deformation of objects. This direction is connected with the need to solve a number of tasks for the aerospace, oil and gas and railway industries, the automotive industry, medicine and robotics, the importance of which increases in the context of the need for the development of measuring technology.

Fiber-optic sensors occupy an important place in the field of sensors due to a number of advantages that distinguish them from their electronic counterparts. A special type is a sensor based on fiber-optic Bragg gratings, which, in addition to the standard functions that characterize fiber-optic sensors, also allows multiplexing, which creates a wide network consisting of dozens of sensors placed in one optical fiber.

Thus, the use of fiber-optic sensors based on FBG in the field of monitoring systems for building structures allows for high accuracy and reliability of monitoring deformations of fasteners of building structures during their operation.

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