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MEASUREMENT OF THE VEER AND ROTATION OF AN OPTICAL FIBRE USING A BRAGG GRATING

Abstract. There is presented a method for measuring the angle of rotation and twisting using a periodic incline of tilted fibre Bragg grating (TFBG) with an inclination angle of 6° recorded in a single-mode optical fibre. It was shown that when the sensor rotates through 180°, the transmittance changes from 0.5 to 0.84 at a wavelength of 1541.2 nm. As a result of measurements, it was found that the highest sensitivity can be obtained for angles from 30 to 70° concerning the necessary orientation. A change in the transmission spectrum occurs for cladding modes that change their intensity with a difference in the polarization of light propagation through the grating. The same design can be used to measure the angle of rotation. The possibility of obtaining a TFBG rotary device at an edge of 200 ° with a length of more than 10 mm has been proved. It allows controlling both the angle of rotation and the twisting of the optical fibre using the manufactured TFBG.

Key words: sensors, fiber optic Bragg gratings, torsion measurement, rotation measurement.

Introduction. The optical measurement of physical quantities in mechanical systems and structures is gaining increasing commercial importance in various industries. Rotation and twisting are very often measured by mechanical supplies. Fibre-optic methods for measuring these values have several significant advantages, such as resistance to environmental influences, the relatively simple placement of sensors on the estimated structures and the possibility of simultaneous measurements in many places. In recent years, veer and rotation sensors have been intensively developed to research new fibre-optic sensor solutions [10, 12].

The first work in the field of fibre-optic rotation sensors appeared in the late 1980s. There are many optical methods for measuring rotation and twisting [1]. Recently, inclined the fibre Bragg gratings (TFBG) [2-4] have been very popular in measuring rotation and other quantities. These gratings use the property of the effect of the polarization of the introduced light – by which are meant the state of polarization (SOP) – on the spectrum of the shell regime. This is because the TFBG structure inhibits the cylindrical symmetry of the optical fibre [5]. TFBG offers all the benefits of standard FBG technologies, such as ease of manufacture and small size. An additional advantage of inclined FBG is a large number of cladding modes visible in a relatively narrow spectral range.

This article describes the use of a single optical fibre generated by an inclined periodic structure for measuring the angle of rotation and twisting of an optical fiber. To perform and analyze rotation and twisting measurements, it is necessary to fix a periodic structure in which the modulation planes of the refractive index are set at a certain angle concerning the normal axis of the optical fibre. Figure 1 shows the actual dimensions of the structure created in this way.

The structure shown in figure 1 was obtained using a laser using the phase mask method, which ensures the propagation of light in such a way that the grid planes are located at an angle = 6° to the normal axis of the fibre. SMF-28 single-mode fibre was previously photosensitized in a hydrogen atmosphere at a pressure of 190 bar and a temperature of 20 °C for ten days. After recording, the grid had a total length of 10 mm.

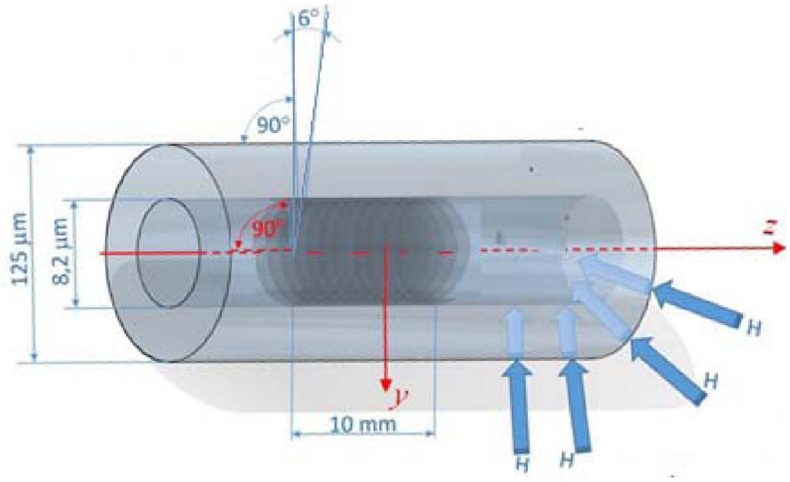

Figure 1 – Dimensions and characteristics of the created design TFBG, used as a rotation and rotation sensor

The structure thus created was then subjected to spectral tests. Figure 2 shows the transmission spectrum of the designed structure. As we can see, it has several resonances for waves shorter than the Bragg wavelength. As can be seen, the maximum height of the minima coming from the shells falls on wavelengths in the region of 1540 nm. This wavelength range, as shown in figure 2, was chosen as a measurement of the angle of veer and angle of rotation. The most significant dynamics of changes was also obtained in this area, in particular, minima from mantle regimes, as well as changes in the rotation and bending of the TFBG structure.

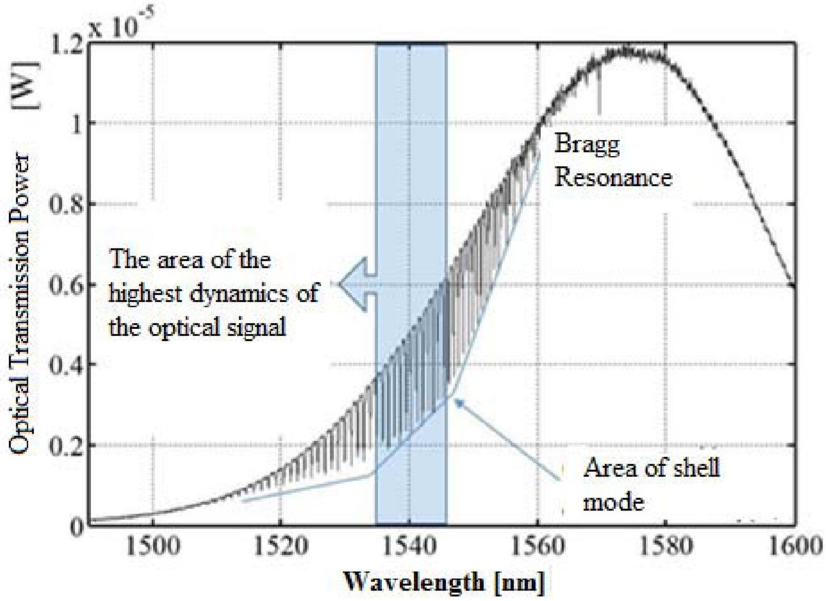

Figure 2 – Transmission spectrum of the created structure. (The core resonance and several mode shell resonances are marked on the characteristics. The wavelength range selected for analysis was marked by a darkened vertical rectangle)

Since it is known that a TFBG fibre responds to changes in the polarization angle of the light inlet into such a fibre [9, 11], this article will show differences in the spectral response of such a system to changes in its rotation and torsion angles.

During the measurements, the optical fibre rotated and twisted (figure 3a). In the case of rotation, both ends of the fibre with the recorded TFBG element turned at the same angle, which led to the rotation of the entire fibre. The length of the TFBG element was LTFBG = 10 mm, and the length of the optical fibre between the right-hand rotating end of the fibre and the TFBG element was 15 mm.

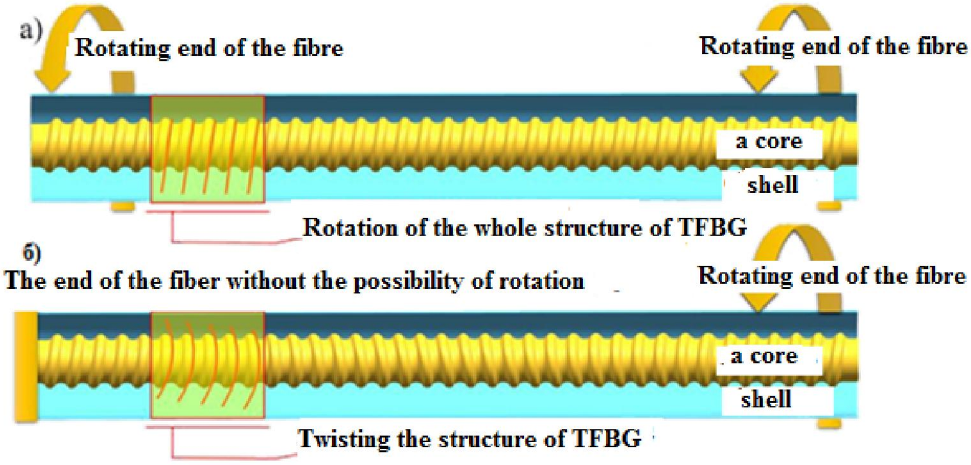

Figure 3 – Tuning and measurement method:
a) rotation, b) twisting, of the optical fiber in which the TFBG structure was recorded

In the case of twisted fibre optic cables, a 10 mm TFBG element is placed directly on the rigidly fixed end of the optical fibre. The distance between the TFBG and the rotating end of the fibre was 30 mm. A single-mode fibre SMF-28 with a diameter of 10.4 μm, a core diameter of 8.2 μm, a sheath diameter of 125 μm and a coating diameter of 242 μm was used. The length of the SMF-28 was 1 m. In both cases, linearly polarized light of a known polarization plane was inserted into the fibre. There was used a light source of SLD luminescent diode with a maximum power of 2.5 mW, a central wavelength of 1550 nm and a passband of 90 nm. The measurement was carried out at a source current of 200 mA and a temperature of 20 °C. The polarization of light was determined and controlled using additional optical elements. In the first case (figure 3a), both ends of the fibre were rotated using the precision shaft of the Thorlabs HFR007 optical fibre through the same angle with an accuracy of two degrees.

The rotation of the fibre caused changes in the energy distribution between the individual mode shells in the TFBG structure. Energy changes were observed using a Yokogawa AQ63370D optical spectrum analyzer. The spectral resolution of the analyzer was 0.02 nm. The optical spectrum was measured in the range from 1490 to 1600 nm. In the second case (figure 3b), the measurements looked similar, but the difference was that only one end of the optical fibre was rotated, which led to the twisting of the optical fibre and TFBG stored in it.

The idea of the measuring system is shown in figure 4. The light from the luminescent diode was directed through the lens (O1) to the polarizer and to the half-wave plate (λ/2), to let incident light pass, controlling only its polarity. Then, through the lens (O2), the light was directed to a single-mode optical fibre with TFBG stored on it. The light was connected between the fibres and the lenses using the x, y, z manipulators from ThorlabsInc. Both reference points (1 and 2) were used to call and control the rotation and twisting of the optical fibre using the TFBG sensor. The signal was measured after passing through

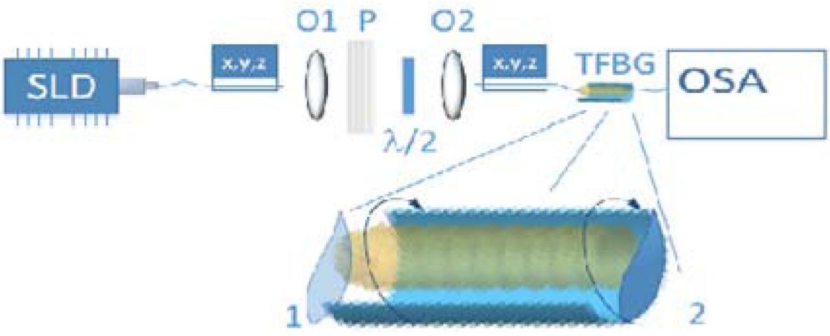

Figure 4 – Rotation angle and measuring system of rotation and rotation

the entire system using an optical spectrum analyzer (OSA). In all measurements, a TFBG grid with an angle θ = 6°, was used; measurements were carried out at a stabilized ambient temperature of 20 ° C and a current SLD of 200.8 mA.

Analysis of the possibility of measuring rotation using inclined periodic structures. The made TFBG structure was subjected to spectral tests in the system, as shown in Figure 4. As a result of changing the angle of rotation of the TFBG fibre, the transmission spectral characteristics were obtained – figure 5 for various fibre orientations.

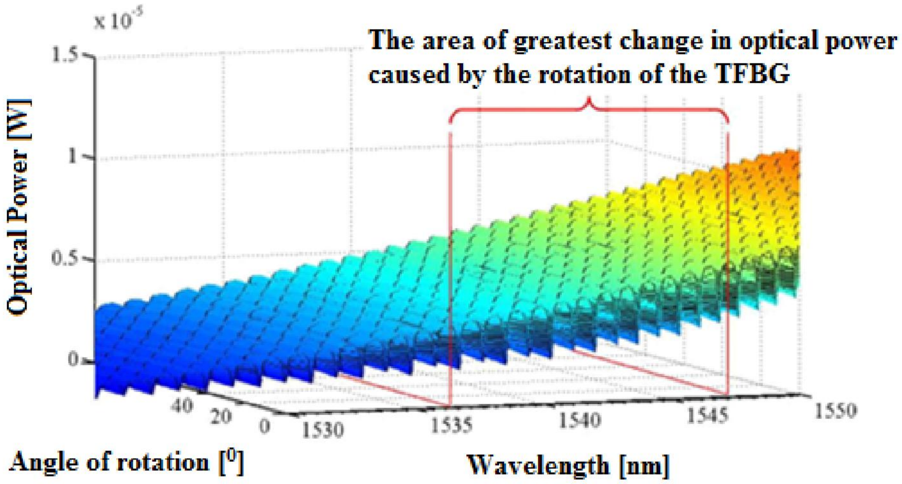

Figure 5 – There is a change in transmitted optical power after passing through TFBG (6 °) at multiple angles of rotation

For a grating with an angle θ = 6° the area of the most extensive transmission changes caused by the rotation of the structure is from 1536 to 1548 nm (figure 5). As a result of preliminary measurements of the transmission spectrum, the wavelength range corresponding to the mode shell was chosen.

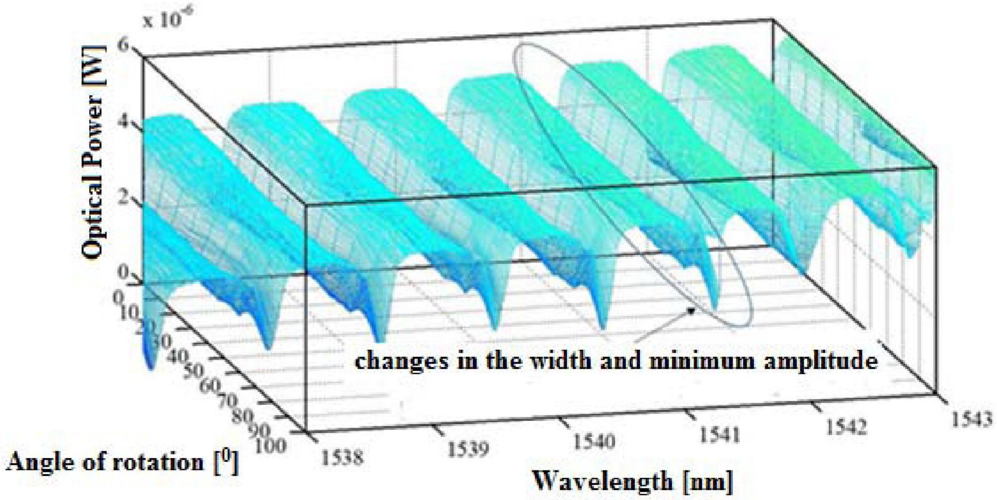

Figure 6 – Change in TFBG transmission characteristics for rotation angles from 0 to 100°

Figure 6 shows the changes in optical power after passing through the TFBG structure with the selected region of the mode chosen shell for further measurements. A preliminary analysis of the spectral characteristics showed the TFBG response to the rotation, which manifests itself in a change in the amplitude of the minima coming from the mode shells at a length of 1542 nm, as well as a difference in the wavelength corresponding to the minima for the mode shells in this wavelength region.

Further studies were carried out in the area of 1542 nm, measuring the shifts of the minima of the spectral characteristics and amplitude changes of the mode shells (figure 7). The TFBG transmittance

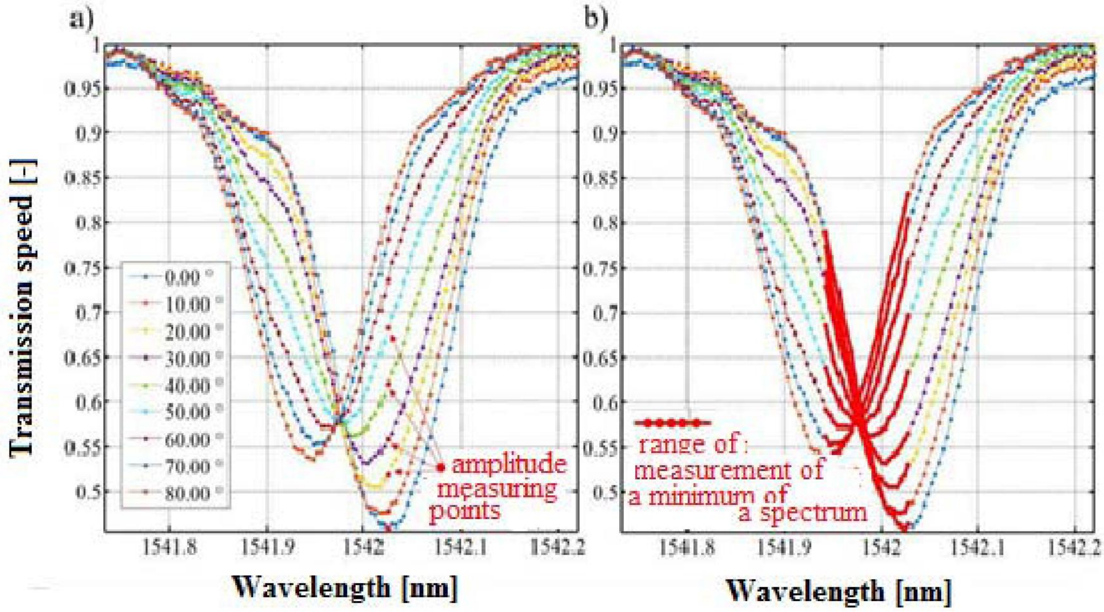

Figure 7 – TFBG rotation effect: a) a difference in the mode amplitude for the selected wavelength, b) a shift in the minimum corresponding to a specific mode in the envelope

changes for a given wavelength are shown in figure 7a. This figure also shows the transmittance measurement points for TFBG (6 °). Figure 7b shows the phenomenon of a shift in the spectrum of the shell mode due to the rotation of the TFBG structure. For practical reasons, this bias is most measured merely by detecting extreme shifts in transmission characteristics. Figure 7b also shows the minimum measurement region of the spectral transmission characteristics.

Figure 8 shows the results of spectral measurements of TFBG fibres rotated from 0 to 80 degrees. The direction of rotation corresponded to the designation in the drawing and was called in work by the so-called right rotation (P).

The part of the spectral range corresponding to the minimum value for small wavelengths (minimum left) is called the S-shaped mode in the literature. The minimum amount indicated on the right is most often stated in the documentation as a P-shaped mode[6-8].As can be seen, the rotation of the fibre optic

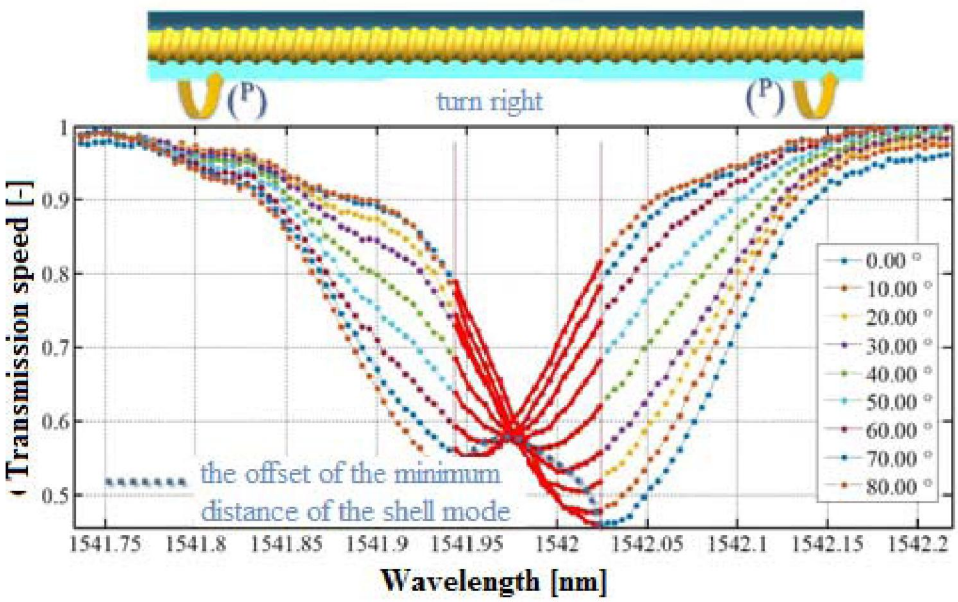

Figure 8 – Transfer characteristics of the fabricated TFBG structure, measured for various rotation angles (P)

cable with TFBG causes a change in the excitation level of the left (S) and right (P) modes propagating in the structure. This is caused by a difference in the coefficient of adhesion between the individual modes. This effect can be used to determine the angle of rotation, for example, by measuring the power value for a given wavelength. For this, a wavelength of 1542.2 nm was chosen (figure 7a), for which a significant change in power occurs due to the rotation of the fiber. This wavelength can be used for indirect measurements of the angle of rotation. According to figure 7a, for the starting position, the transmittance takes a value below 0.5. Rotating the structure by 80 ° increases the transmittance for the selected wavelength even up to 0.85. Moreover, in these ranges of rotation of the fibre, a minimal change in the transmission characteristics is noticeable(fig.7б and figure 8). The wavelength corresponding to the minimum transmission for the fibre in the reference position (veer angle is 0) is 1542.025 nm and moves as the veer angle increases in the direction of short waves to 1541.94 nm at a veer angle of 80.

The obtained spectral characteristics also have regions where the power value does not change (or changes insignificantly) during rotation. Individual modes exchange energy, but the power value for wavelengths, for example, 1541.975 nm (figure 8), varies very little. Any change in the power value for these wavelengths is the result of a change in temperature. If the temperature changes during the measurement, the whole spectrum shifts, which leads to a shift in power for these specific wavelengths. This phenomenon is called the temperature effect, which should be taken into account in spectral measurements of TFBG under conditions of a variable angle of polarization of light.

Conclusion. In this article, we demonstrate the possibility of measuring the degree of rotation and twisting of an optical fibre using a TFBG structure recorded on it with an inclination angle of 6°. It was shown that when the sensor rotates through 180°, the transmittance changes from 0.5 to 0.84 at a wavelength of 1541.2 nm. It is proved that the highest sensitivity can be obtained in the central part of the processing characteristics, for angles from 30 to 70°. It has been shown that the same design can also be used to measure the angle of rotation. TFBG responds to twisting along a 200° cable with a length of 10 mm (from 100 to +100°) by changing the transmittance in the range from 0.39 to 0.89 at a wavelength of 1541.4 nm. This allows controlling both the veer angle and the twisting of the optical fibre using the inscribed TFBG.

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БРЭГГ ТОРЫН ҚОЛДАНУ АРҚЫЛЫ ОПТИКАЛЫҚ ТАЛШЫҚТЫҢ БҰРЫЛУЫ МЕН АЙНАЛУЫН ӨЛШЕУ

Аннотация. Бір модалы оптикалық талшыққа бекітілген, 6° бұрышқа иілген периодты көлбеу талшықтық оптикалық Брэгг торын қолдана отырып талшықты бұрылу және айналу бұрышын өлшеу әдісі ұсынылған. Датчик 180° айналғанда, 1541,2 нм толқын ұзындығында өткізу коэффициенті 0,5-тен 0,84-ге дейін өзгеретіні байқалады. Өлшеу нәтижелері бойынша ең жоғары сезімталдықты қалаған бағытқа қатысты 30°-дан 70°-қа дейінгі бұрыштар үшін алуға болатындығы анықталды. Өткізу спектрінің өзгерісі тор арқылы өтетін жарықтың поляризациясындағы айырмашылығымен өз қарқындылығын өзгертетін қабық модалары үшін орын алады. Сол құрылымды айналу бұрышын өлшеу үшін қолдануға болады. Ұзындығы 10 мм-ден асатын 200° бұрышқа бұрылатын периодты көлбеу талшықтық оптикалық Брэгг торын алу мүмкіндігі дәлелденді. Мұның бәрі сізге бұрылу бұрышын ғана емес, сонымен қатар жасалған ПОБТ көмегімен оптикалық талшықты бұрауды басқаруға мүмкіндік береді.

Түйін сөздер: датчиктер, талшықтық оптикалық Брэгг торы, бұруды өлшеу, айналуды өлшеу.

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ИЗМЕРЕНИЕ УГЛА ПОВОРОТА И ВРАЩЕНИЯ ОПТИЧЕСКОГО ВОЛОКНА С ИСПОЛЬЗОВАНИЕМ БРЭГГОВСКОЙ РЕШЕТКИ

Аннотация. Представлен метод измерения угла поворота и скручивания с использованием периодической наклонной волоконно-оптической решетки Брэгга (ВОРБ) с углом наклона 6°, записанной в одномодовое оптическое волокно. Показано, что при вращении датчика на 180° коэффициент пропускания изменяется с 0,5 до 0,84 при длине волны 1541,2 нм. В результате измерений было установлено, что наибольшую чувствительность можно получить для углов от 30 до 70° по отношению к базовой ориентации. Изменение спектра пропускания происходит для модов оболочки, которые изменяют свою интенсивность с изменением поляризации распространения света через решетку. Такая же конструкция может быть использована для измерения угла поворота. Доказана возможность получения поворотного устройства ВОРБ на угол 200° длиной более 10 мм. Это позволяет контролировать как угол поворота, так и скручивание оптического волокна с помощью изготовленного TFBG.

Ключевые слова: датчики, волоконно-оптические брэгговые решетки, измерение кручения, измерение вращения.

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