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INVESTIGATION OF ADDITIONAL LOSSES OF FIBER-OPTIC CONDUCTORS OF TYPE G-652 THAT OCCUR DURING BENDING

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Abstract

One of the problems of modern information transmission systems is the introduction of new methods of protecting information transmitted over fiber-optic transmission lines. Currently, new methods of unauthorized access are emerging, which are being improved and developed every year. Within the framework of this work, studies of additional losses during bending of the optical fiber were carried out in order to create an automatic control system for additional losses that occur during mechanical action leading to its bending. For this purpose, practical experiments were conducted to measure losses in optical fiber with multiple bends and a computer program was created based on the data obtained. With the help of this program, it is possible to estimate additional losses in the optical fiber when the wavelength changes from 1310 to 1625 nm and the bending angle indicators from 45 to 135 degrees. The program also allows you to automatically approximate the values of additional losses occurring in the optical fiber with different variations of different bending angles and their number. The study of additional losses will allow in the future to develop an automatic control system based on changes in the indicators of additional losses and, when they change, issue a warning signal about possible unauthorized connection to a fiber-optic cable.

Keywords: fiber-optic transmission lines, optical fiber, unauthorized access, light wave, fashion, optical reflectometer, additional losses

Introduction

Currently, fiber optics is developing quite intensively and for many years the signal transmission range, bandwidth, speed, reliability and other parameters have been growing. There is not yet a sufficient alternative to its use in data transmission systems and measuring equipment. Due to the widespread use of fiber-optic transmission lines (FOTL), there is a problem of protecting the information transmitted over them, and there is also a need to improve the efficiency of work. Analysis of possible channels of information leakage as a result of unauthorized access (UA) is of paramount importance, it is necessary to improve the methods and means of protection of FOTL. Initially, FOTL have a higher degree of protection of information from unauthorized access, compared with coaxial communication cables and wireless data transmission systems, this is due to the physical principles of electromagnetic wave propagation in the fiber, which cannot be intercepted without disrupting the data transmission process. In an optical fiber (OF), an electromagnetic wave extends beyond the fiber at a distance of no more than a wavelength in the absence of external influence on the fiber. This means that the OF does not emit electromagnetic waves into the surrounding space and the information cannot be detected, as when transmitting over a copper cable, even containing a protective shield. OF has an order of magnitude lower level of signal attenuation, compared to other directional data transmission systems. There is one peculiarity when bending occurs, part of the optical power of the light wave or mode propagating through the core of the S falls into the shell and leaves the boundaries of the interface. Accordingly, the energy of the light wave or mode is lost during bending, the smaller the radius, the higher the losses, and the greater the number of bends, the greater the additional losses introduced. The OF has a diameter of 125 microns and, when stretched, has a strength exceeding a steel thread of a similar diameter, but when bending less than the permissible angle, which is set for each type of OF separately, cracks appear in it, which leads to its destruction. With mechanical action on the OF, a micro-bending and photoelastic effect occurs, in which the additional losses introduced increase. The methods of reading information are based on the creation of a bend or micro-bend and the removal of a part of the light wave from the core to the outside. At the same time, you need to install a photodetector that will read the information. In this case, the attenuation of the signal is quite difficult to control visually, respectively, it requires the development of methods and automatic means of controlling additional losses of the FOTL to increase the level of information protection. Usually, the attenuation of the signal at a wavelength of light with a length of 1550 nm will be about 0.22 dB / km, when bending occurs, additional losses appear, which increases the attenuation of the signal.

Materials and methods of research

In the course of the literary analysis, an overview of the principles of operation of the OF, as well as the use of fiber-optic technologies in communication systems was carried out [1]. In the collection [2], methods and technologies of FOTL laying, crossover equipment, the current state of fiber-optic technology and its prospects were considered. Fiber-optic measuring systems are widely used in the market of measuring systems, [3] describes fiber-optic sensors and systems, as well as the principles of their construction. Field tests of a distributed fiber-optic intrusion sensor system for long perimeters [4] and fiber-optic interferometric Michelson sensors [5] were considered. The results of experimental studies of a sensor based on a high-pressure photonic crystal fiber were studied [6]. There is information on the development and implementation of a new type of pressure sensor based on a fiber-optic Bragg grid [7], and materials on the current state of fiber-optic pressure sensors were also considered [8]. In the literature review, articles were considered concerning losses in the OF during bending, namely, the results of the study of additional losses in the OF under mechanical action [9], as well as those arising in the OF during its multiple bends in the wavelength range of 1310 nm, 1550 nm and 1625 nm [10] were obtained.

As a result of the literature review, it turned out that the most important is the influence of the bends of the OF on the attenuation of the signal and the occurrence of additional radiation power losses (modes) during the transmission of information. As mentioned earlier, when bending the OF, additional energy losses appear, which can be fixed, which means that an automatic control system can be built. These losses grow rapidly after reaching a certain critical bending radius, after overcoming which the OF can collapse, it is about 3-10 mm for different types of fibers. The critical radius is very small (only a few millimeters) for fibers with a high numerical aperture, whereas the permissible bending radius is much larger (often tens of centimeters) for fibers in a single-mode mode with a large transverse mode area. It has been found that bending losses increase with increasing wavelength, respectively, there is a difference in losses at 1310 and 1550 nm. This circumstance will be taken into account when conducting research. The increase in fiber bending losses at long wavelengths limits the transmission range of single-mode fibers. Bends are divided into macro- and micro-bends. Micro-bends are characterized by small local violations of the straightness of the fiber caused by structural and technological inhomogeneities that may occur during the manufacture of fiber, as well as the laying and manufacture of cable. Macro-bends of the fiber appear as a result of their twisting along the length of the cable and when winding on the drum. Losses are caused by leakage or radiation of guided modes and become unacceptably large when the radius of curvature of the bend is reduced to critical values. The critical bending radius of the fiber is approximately calculated by the formula:

$$R_{cr} \approx \frac{3n_1^2\lambda}{4\pi(n_1^2-n_2^2)^{3/2}}, \text{ mm} \tag{1}$$

The OF is able to withstand bending at an angle of ± 90 ° with a radius of no more than 20 times the outer diameter at normal ambient temperature and at ambient temperature not lower than -10 ° C. At the stand, the minimum bending radius of the OF was within the permissible range and was 3 mm with a diameter of 125 microns. As experience has shown, attackers create a situation associated with bending or micro-bending of the fiber using special devices for reading information.

At the same time, some methods do not imply the removal of the external protective shell, which greatly facilitates the process of stealing information. Next, a study was studied in which the dependence of attenuation on the wavelength and bending radius was determined. For practical experiments, a laboratory stand was developed, shown in Figure 1.

An optical reflectometer Yokogawa AQ1200E (Japan) was used to measure the losses in OV with multiple bends close to the critical radius.

Which is an optical reflectometer of the Optical Time Domain Reflectometer (OTDR) standard and is used in telecommunications for operational analysis of optical cable networks, including determining the amount of additional losses (Figure 1).

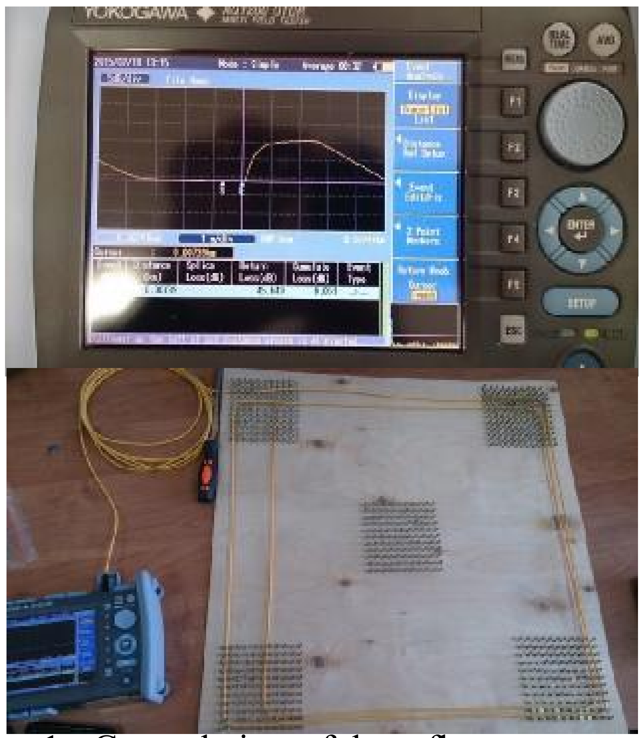

Figure 1 - General view of the reflectometer and the stand

The result of the measurement is the average values of additional losses introduced by various connection devices, welding and bending sites. The measurement data are presented in the form of numerical values of instantaneous readings and averaged values, as well as a reflectogram of the FOTL site.

The measurement results were entered into a table and processed using a computer program. In order to ensure the reliability of the results of experimental studies, the required number of repetitions is set based on the coefficient K_{var} and the required degree of accuracy. The numerical study was carried out using the Wolframalpha program. This program is an interactive system that performs the processing of experimental results and is focused on working with data arrays.

The required number of repetitions of experiments is calculated based on the coefficient of variation and is determined by the formula:

$$K_{var} = \frac{100 \cdot \delta 0}{\chi}, \% \quad (2)$$

where δ_i - is the mean square deviation of the coefficient K_{var} and the required degree of accuracy;

χ - arithmetic mean.

The standard deviation is determined by the formula:

$$\delta = \sqrt{\frac{\sum \delta_i^2}{N-n}}, \quad (3)$$

where δ_i - the deviations of individual results from the group averages;

N - the total number of experiments;

n - the number of groups of experiments.

The K_{add} value is used to establish the required number of experiments, measured as a percentage. If the coefficient of variation K_{var} is known for this test method, then it is possible to determine the required number of experiments with a reliability of 0.95. Next, 30 measurements of additional losses arising in the OF under mechanical action are randomly selected to construct the Weibull distribution. The confidence probability is P=0.95, the quantile of the Student's distribution is t = 2.0095 for a given confidence probability with the number of degrees of freedom n, k = n - k (n, k is the number of suspicious observation results). The relative measurement error δ = 3.5%.

Results.

4.1 Results of laboratory studies of fiber-optic conductor type G-652

Using the laboratory bench presented earlier in Figure 1, empirical studies of additional losses arising in a single-mode G-652 standard with a length of 10 meters, with a core and shell size of 9/125 microns, were carried out. Three wavelengths of optical radiation were used: 1310, 1550 and 1625 nm. The data obtained were processed using a computer program that performs automatic approximation of the results. The graphs of the experimental results are presented below. The graph (Figure 2) shows the dependence of the growth of additional losses with an increase in the number of bends of the OF, the wavelength is 1310 nm. The number of bending angles was 7, and their angle was 90 degrees.

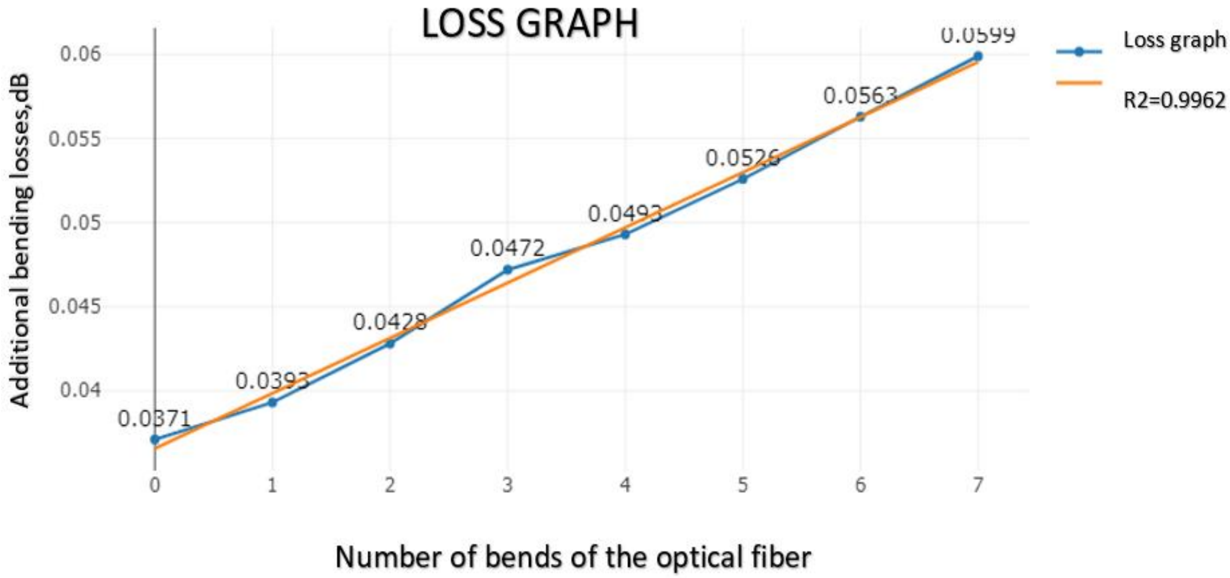

Figure 2 - Graph of the dependence of the growth of additional losses with an increase in the number of bends of the OF at a wavelength of 1310 nm

Figure 3 shows the dependence of the growth of additional losses with an increase in the number of bends of the S, the wavelength is 1550 nm. The number of bending angles was 7, and their angle was 45 degrees.

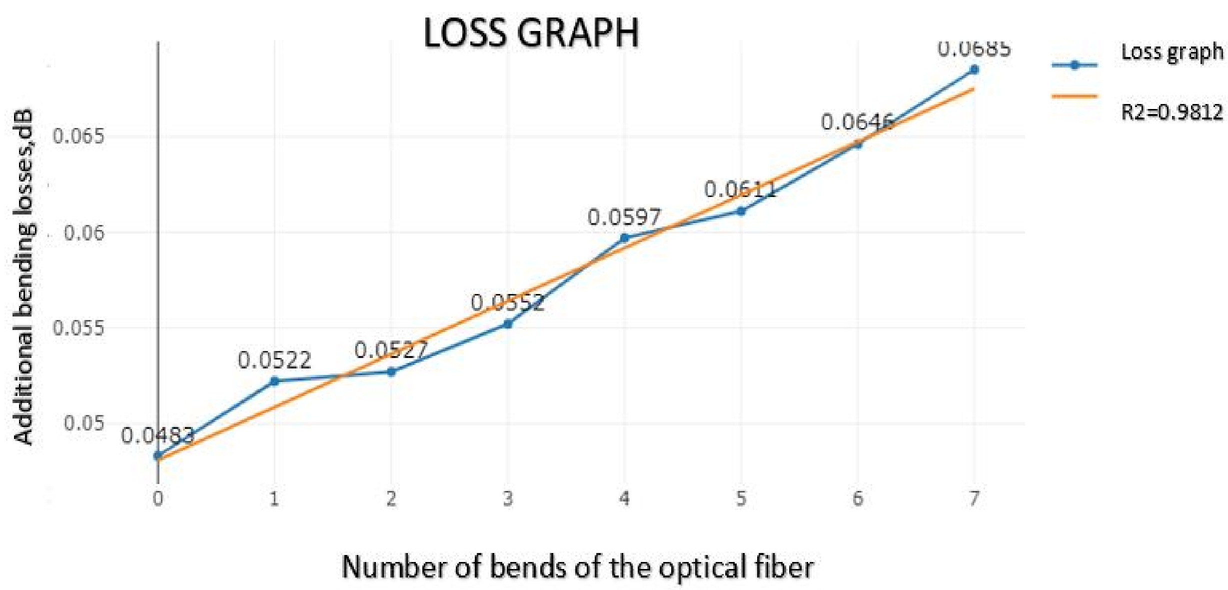

Figure 3 - Graph of the dependence of the growth of additional losses with an increase in the number of bends of the OF at a wavelength of 1550 nm

Figure 4 shows the dependence of the growth of additional losses with an increase in the number of bends of the S, the wavelength is 1625 nm. The number of bending angles was 7, and their angle was 135 degrees.

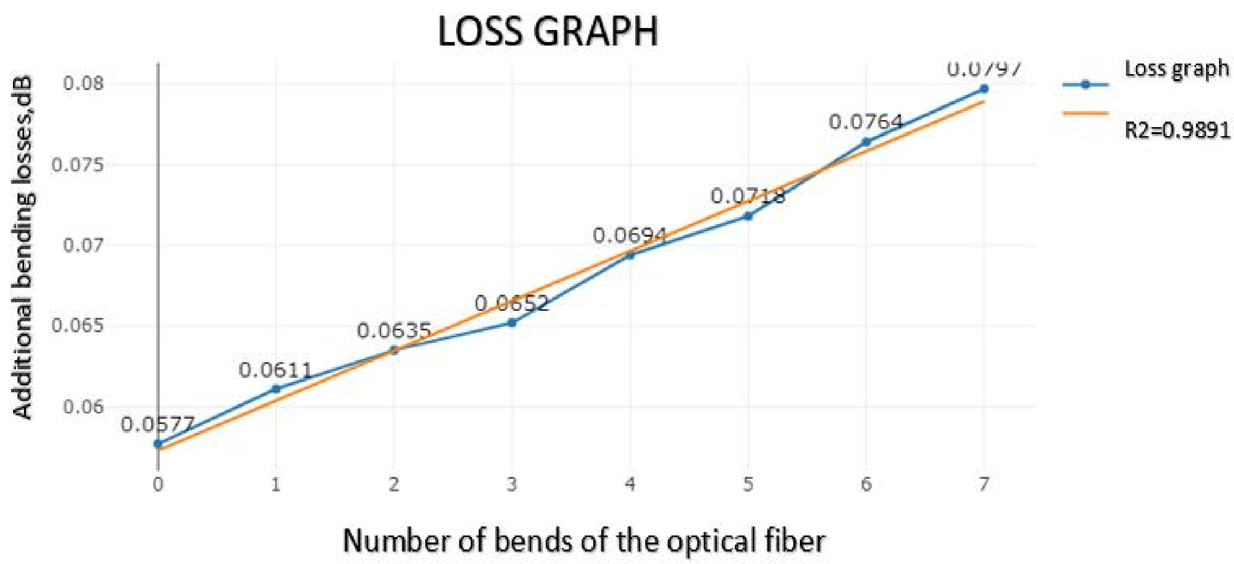

Figure 4 - Graph of the dependence of the growth of additional losses with an increase in the number of bends of the OF at a wavelength of 1625 nm

Bending losses can reach a maximum of 0.02 dB or more, and they are different at different wavelengths. The longer the transmission is at the wavelength, the greater the bending loss. Accordingly, using the data obtained, it is possible to develop an automatic system for monitoring additional losses and, if they increase, there is a possibility of unauthorized connection to a fiber-optic cable.

4.2 Software development results

A program has been developed with the help of which it is possible to estimate losses in optical fiber with multiple bends of a critical radius. The program uses data obtained as a result of empirical research, and automatically guards approximations, as well as conducts regression analysis of the results. The program window is shown in (Figure 5).

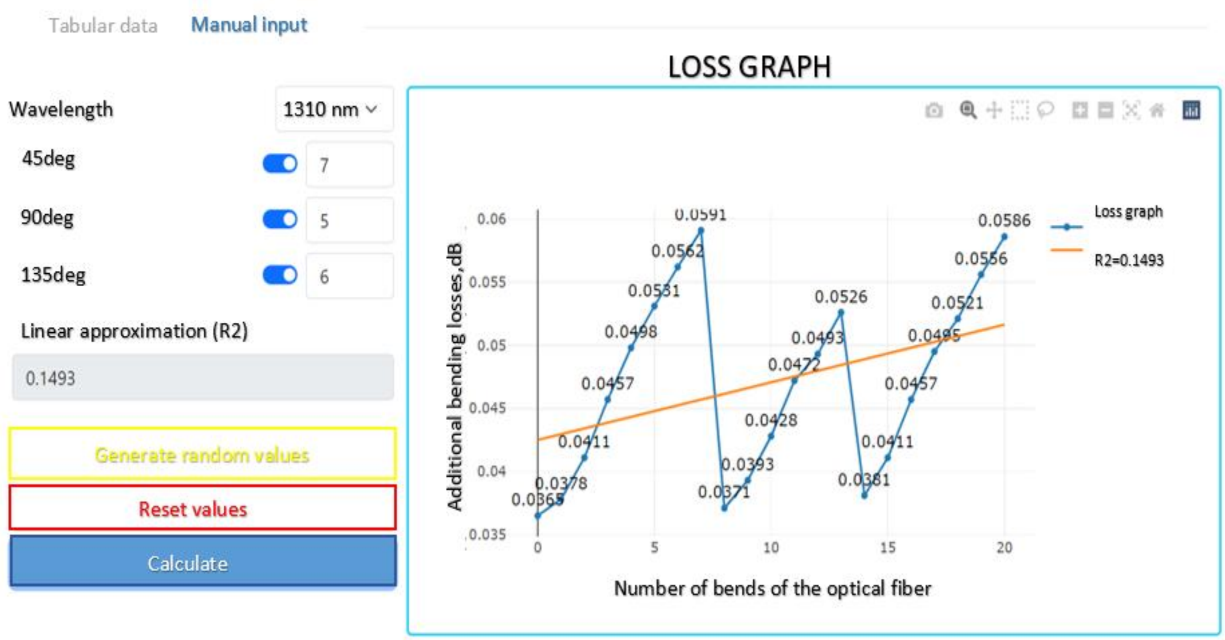

Figure 5 - General view of the interface

For the mathematical description of power losses due to attenuation, the parameter attenuation block a, measured on a segment of 1 km, is used in the s. It is expressed in dB/km and is determined by the formula 4:

$$a = \frac{10}{L}\log\{\frac{P(l_1)}{P(l_2)}\} \quad (4)$$

$P(l_1)$, $P(l_2)$ – optical power measured in S, at points l1 and l2 distant from each other by L

Attenuation increases exponentially with increasing fiber length, limiting the transmission range. An increase in attenuation by 3 dB corresponds to a decrease in the power of the proposed signal by 50%.

This program has two input states, when the data for calculation is presented based on the results of practical experiments and is approximated automatically or by manually entering other data that needs to be processed.

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Next, Figure 6 shows the method of manual input. With this method, losses are calculated by linear regression and are represented as a mathematical function. All values are entered manually, and the program performs automatic data processing and performs approximation. Coefficient A - denotes the slope of the line, coefficient B - its shift, value X - an independent variable. Linear approximation (R2) is used to find coefficients A and B of linear regression so that all experimental points lie closer to the straight line. You can also add multiple values of the X variable

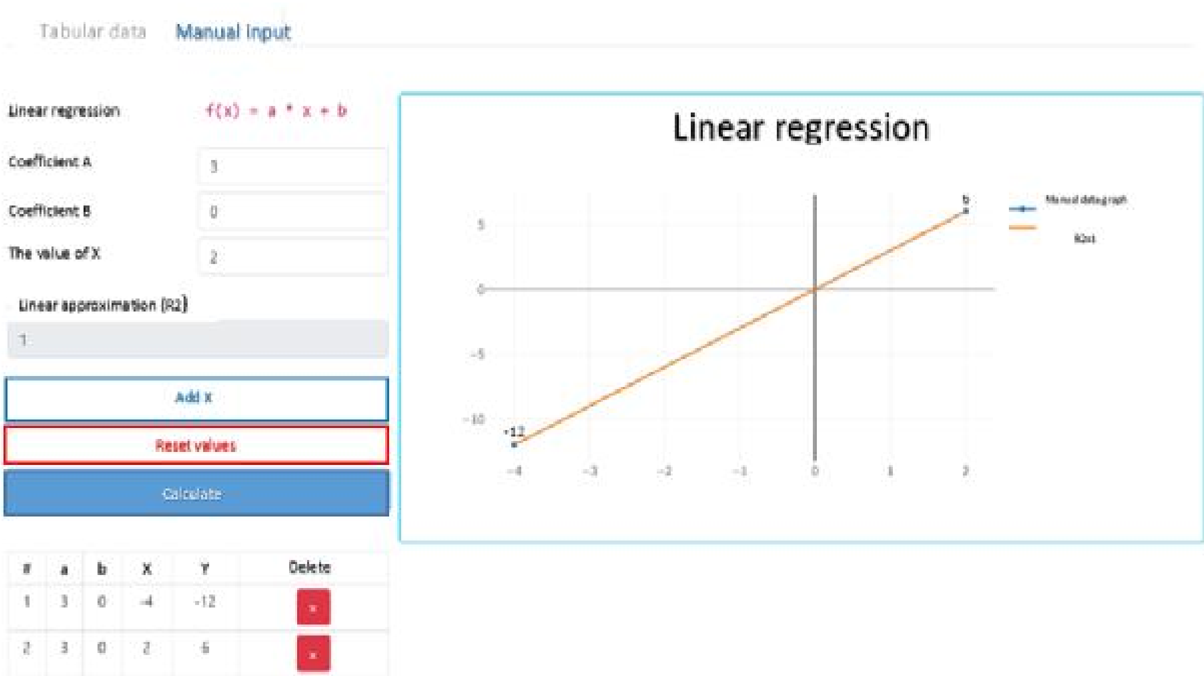

Figure 6 - Manual input interface

The program can also perform automatic generation of the number of bends in random order. There are buttons for resetting the calculation results and performing the calculation.

Discussion of the results and conclusion

As a result of the study, new scientifically based results were obtained that are valuable for creating an automatic control system for additional losses in the OF at various bending variations. In the course of the study, multiple data were obtained, on the basis of which a mathematical model of the dependence of losses on the number of catches, types of angles and wavelength was built, which formed the basis of the program. The program allows you to calculate additional losses on a fiber-optic cable with different numbers of bends. If we analyze the summary diagrams, then with an increase in the wavelength of light, additional losses in the OF decrease, and with an increase in bending they increase. Accordingly, with an increase in the number of bends, losses increase. The program operates under the boundary conditions of the wavelength from 1310 to 1625 nm and the maximum number of bends is no more than 7. The values of the specified angles are strictly fixed from 45 to 135 degrees and do not change. The program also allows you to automatically approximate the values of additional losses that occur in the optical fiber with different variations of different bending angles and their number. Bending losses can reach about 0.01 dB or more, and they are different at different wavelengths. The study of additional losses will allow in the future to develop an automatic control system based on changes in the indicators of additional losses and, if they change, issue a warning signal about possible unauthorized connection to a fiber-optic cable.

References

1 Bailey D., Wright E. Fiber optics. Theory and practice [Text] / D. Bailey, Wright E. // M.: Kudits-Obraz, 2006. 320 p.

2 Dmitriev S.A. Fiber-optic technology: current state and prospects [Text] / S.A. Dmitriev, N.N. Slepov // Moscow: LLC "Fiber-optic technology", 2005. 576 p.

3 Sokolov A.N. Fiber-optic sensors and systems: principles of construction, possibilities and prospects [Text] / Sokolov A.N., Yatseev V.A. // Measuring technique. Light Wave, 2006. No. 4. pp. 142-153.

4 Juarez J. S. Field tests of a distributed fiber-optic intrusion sensor system for long perimeters [Text] / J.S. Juarez and H.F. Taylor // Applied optics. - 2007. - Volume 46, No. 11. - Pp.1968-1971.

5 Shi-Chu Huang and Herman Lin, methods of processing counting signals and normalization of the counting level of Michelson fiber-optic interferometric sensors insensitive to polarization [Text] / Shi-Chu Huang and Herman Lin // Applied Optics. - 2006. - Volume 45, No. 35. - pp.8832-8838.

6 Numerical and experimental studies for a photonic crystal high-pressure sensor based on fiber Giuliano G. Hayashi [Text] / Giuliano G. Hayashi, M.B. Cristiano Cordeiro, Marcos A. R. Franco and Francisco Sircilli / Citation: Proceedings of the AIP Conference 1055, 133 (2008); doi: 10.1063/1.3002521 DOI:https://doi.org/10.1063/1.3002521

7 František Urban et al., Pressure sensor design based on transverse deformation of the Bragg fiber-optic lattice, Sensors [Text] / František Urban et al // 2010, 10, 11212-11225

8 Hashemian H.M. Assessment of fiber optic pressure sensor [Text] / H.M. Hashemian, C.L. Black, and J.P. Farmer // United States: N. p., 1995. Web. doi:10.2172/71391.

9 Yurchenko A.V., Gorlov N.I., Mekhtiev A.D., Kovtun A.V. Investigation of additional losses arising in an optical fiber during its multiple bends in the wavelength range of 1310 nm, 1550 nm and 1625 nm [Text] / A.V. Yurchenko and other // Nauka o IOP. Physical journal. 2016. V. 671. DOI:10:1088/1742-6596/671/1/012001. DOI:10:1088/1742-6596/671/1/012001.

10 Yurchenko A.V., Mehtiev A.D., Bulatbayev F.N., .Neshina Yu.G.,.Alkina A.D., Madi P.S. Investigation of additional losses in optical fibers under mechanical action. [Text] / A.V. Yurchenko and other // III International Conference "Cognitive Robotics" IOP Conf. Series: Materials Science and Engineering 516 (2019) 012004 IOP publication DOI:10.1088/1757-899X/516/1/012004

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ИІЛУ КЕЗІНДЕ ПАЙДА БОЛАТЫН G - 652 ТИПТІ ТАЛШЫҚТЫ ӨТКІЗГІШТЕРДІҢ ҚОСЫМША ШЫҒЫНДАРЫН ЗЕРТТЕУ

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Түйін

Қазіргі заманғы ақпарат беру жүйелерінің проблемаларының бірі талшықты-оптикалық беру желілері арқылы берілетін ақпаратты қорғаудың жаңа әдістерін енгізу болып табылады. Қазіргі уақытта жыл сайын жетілдіріліп, дамып келе жатқан рұқсатсыз кірудің жаңа тәсілдері пайда болуда. Осы жұмыс аясында оның иілуіне әкелетін механикалық әсер ету кезінде пайда болатын қосымша шығындарды бақылаудың автоматты жүйесін құру үшін оптикалық талшықты иілу кезіндегі қосымша шығындар туралы зерттеулер жүргізілді. Ол үшін бірнеше иілу кезінде оптикалық талшықтағы шығындарды өлшеу үшін практикалық тәжірибелер жүргізілді және алынған мәліметтер негізінде компьютерлік бағдарлама құрылды. Осы бағдарламаның көмегімен толқын ұзындығы 1310-нан 1625 нм-ге дейін және иілу бұрышының көрсеткіштері 45-тен 135 градусқа дейін өзгерген кезде оптикалық талшықтағы қосымша шығындарды бағалауға болады. Сондай-ақ, бағдарлама әртүрлі иілу бұрыштары мен олардың санының әр түрлі өзгеруімен оптикалық талшықта пайда болатын қосымша шығындардың мәндерін автоматты түрде жақындатуға мүмкіндік береді. Қосымша ысыраптарды зерттеу болашақта қосымша ысыраптар көрсеткіштерінің өзгеруіне негізделген автоматты бақылау жүйесін әзірлеуге және олар өзгерген кезде талшықты-оптикалық кабельге рұқсатсыз қосылу мүмкіндігі туралы ескерту сигналын беруге мүмкіндік береді.

Кілт сөздер: талшықты-оптикалық тарату желілері, оптикалық талшық, рұқсатсыз кіру, жарық толқыны, мода, оптикалық рефлектометр, қосымша шығындар

ИССЛЕДОВАНИЕ ДОПОЛНИТЕЛЬНЫХ ПОТЕРЬ ВОЛОКОННО-ОПТИЧЕСКИХ ПРОВОДНИКОВ ТИПА G-652, ВОЗНИКАЮЩИХ ПРИ ИЗГИБЕ

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Аннотация

Одной из проблем современных систем передачи информации является внедрения новых методов защиты информации передаваемой по волоконно-оптическим линиям передачи. В настоящее время появляются новые способы несанкционированного доступа, которые с каждым годом совершенствуются и развиваются. В рамках данной работы были проведены исследования дополнительных потерь при изгибе оптического волокна с целью создания автоматической системы контроля дополнительных потерь, которые возникают при механическом воздействии приводящим к его изгибу. Для этого были проведены практические опыты для измерения потерь в оптическом волокне при множественных изгибах и на основе полученных данных была создана компьютерная программа. С помощью данной программы можно оценить дополнительные потери в оптическом волокне при изменении длины волны от 1310 до 1625 нм и показателей угла изгиба от 45 до 135 градусов. Также программа позволяет автоматически аппроксимировать значения дополнительных потерь возникающих в оптическом волокне при различной вариации различных углов изгиба и их количества. Исследование дополнительных потерь позволят в будущем разработать автоматическую систему контроля, основанную на изменении показателей дополнительных потерь и при их изменениях выдавать предупреждающий сигнал о возможном несанкционированном присоединении к волоконно-оптическому кабелю.

Ключевые слова: волоконно-оптические линии передачи, оптическое волокно, несанкционированный доступ, световая волна, мода, оптический рефлектометр, дополнительные потери