UDC 728.22:681.7 DOI:10.31650/2786-7749-2025-3-274-288

FIBER-OPTICAL EQUIPMENT FOR TECHNICAL DIAGNOSTICS OF HIGH-RISE ARCHITECTURAL STRUCTURES

[1]**Sandler A.**
sa@onma.edu.ua, ORCID: 0000-0002-0709-0542
National University "Odessa Maritime Academy"
str. Didrichson, 8, Odessa, 65052, Ukraine

Abstract. The problem of ensuring reliable perception of design loads by load-bearing building structures after the negative impact of hydrometeorological or destructive operational factors is especially acute with the increase in the number of storeys of architectural structures. This task is necessarily taken into account at the design stage. However, in the calculations it is not possible to take into account the actual state of the load-bearing structure of the building after an earthquake, storm or fire. The modern concept of "operation to a pre-failure state" is based on various methods of forecasting the technical condition, in particular - identification of destruction at the initial stage of their development. The practical use of this concept requires the introduction of new, more effective, easy-to-use, automated means and devices for technical diagnostics and forecasting the technical condition of building elements and structures and significantly complicates monitoring procedures. Trends in the development of modern methods of operation show that it is the use of reliable, verified, insensitive to disturbances diagnostic means and devices that are organically built into the information and measuring system that ensure high operational efficiency and reliability of the functioning of architectural structures. Existing means and devices for diagnosing the technical condition of architectural structures operate under conditions of concentrated influence of destabilizing factors. It is these disturbances that do not allow for effective diagnostics and forecasting of the technical condition of architectural structures that meet modern operational requirements. Analysis of known solutions proves that for modern monitoring of technical condition new means of diagnostics and forecasting are in demand, namely - fiber optic devices insensitive to most operational destabilizing factorsThat is why the scientific task of creating diagnostic tools that function in difficult operating conditions and are adapted for continuous, long-term and reliable monitoring of the condition of architectural structures under the action of concentrated influence of destabilizing factors is relevant and in demand by construction companies, the solution and practical use of which significantly increases the level of safety of super-tall buildings. To overcome a certain restraint in the improvement of measuring equipment, a direction of development of measuring transducers based on the use of optical radiation for recording physical effects has been formed. The use of unique properties of optical materials is an effective solution for the creation of fiber-optic measuring transducers and information and measuring system communication lines. Technological breakthrough in the production of special optical glass has allowed it to largely surpass the properties of known materials.

The task is solved by providing a device for determining angular displacements, which contains a unit for recording and processing information, a laser emitter, a photodetector, and which is characterized in that the laser emitter and the compensating interferometer connected to the photodetector are connected to the primary branches of a two-way optical splitter, the secondary branches of which contain optical filters and are connected to planar light guides, which contain fiber Bragg gratings and are fixed along the internal space of the building element parallel to and perpendicular to its planes.

Keywords: supertall building, technical monitoring, fiber optic sensor

Statement of the problem in general and its connection with important scientific and practical tasks. The problem of ensuring reliable perception of design loads by load-bearing building structures after the negative impact of hydrometeorological or destructive operational factors is especially acute with the increase in the number of storeys of architectural structures. This task is necessarily taken into account at the design stage. However, in the calculations it is not possible to take into account the actual state of the load-bearing structure of the building after an earthquake, storm or fire (Fig. 1).

Fig. 1. Supertall skyscraper with a height of 828 meters

Therefore, today the most effective way to diagnose, predict and prevent emergency situations is constant monitoring of the technical condition of architectural structures at all stages of their life cycle. Analysis of world experience shows that it is advisable to equip all designed high-rise buildings with monitoring systems for the condition of load-bearing structures, which should work together with other technical diagnostic and control systems, forming a single automated information and measuring system (IMS). This IMS allows real-time transmission of information to emergency dispatch services for assessment, prevention and elimination of the consequences of destructive factors in order to timely notify and manage the evacuation of residents or personnel in the building [1, 2].

Geodetic methods allow determining the movement of building structures in space and measuring their settlements. The data obtained correspond to the state of the structures at the time of measurement, i.e. these methods are implemented with single measurements and do not provide constant information on the dynamics of the behavior of the building structure. Therefore, an important aspect of the implementation of reliable and informative monitoring systems is their automation, which ensures continuous instrumental control.

Geodetic monitoring systems must also meet the following conditions:

- ensure a long period of trouble-free operation. Often, objects located far from populated areas need monitoring. Maintenance of such systems requires the involvement of specialists who may not be nearby. Therefore, just calling them to the site to restore the operability of monitoring devices will require large material costs;
- ensure autonomous operation in the absence of power supply;
- ensure data transmission in the absence of wired communication lines and mobile Internet;
- be repairable without the need to transport to specialized service centers [3].

Formulation of the objectives of the article. The aim of the article is to determine the ways of implementing modern fiber-optic technologies in the process of designing and constructing supertall structures. To achieve the set goal, the following tasks were solved:

- determining the potential of fiber-optic technologies, taking into account both positive and negative consequences;

- creating a fiber-optic sensor for technical monitoring of supertall structures;

- determining the range of challenges and limitations associated with the implementation of these technologies in the educational process;

- formulating recommendations for teachers, administrators of educational institutions and stakeholders.

An analysis of recent research and publications that have begun to address this issue and highlight previously unsolved parts of the overall problem. The modern concept of "operation to a pre-failure state" is based on various methods of forecasting the technical condition, in particular - identification of destruction at the initial stage of their development. The practical use of this concept requires the introduction of new, more effective, easy-to-use, automated means and devices for technical diagnostics and forecasting the technical condition of building elements and structures and significantly complicates monitoring procedures. Trends in the development of modern methods of operation show that it is the use of reliable, verified, insensitive to disturbances diagnostic means and devices that are organically built into the IMS that ensure high operational efficiency and reliability of the functioning of architectural structures. Existing means and devices for diagnosing the technical condition of architectural structures operate under conditions of concentrated influence of destabilizing factors. It is these disturbances that do not allow for effective diagnostics and forecasting of the technical condition of architectural structures that meet modern operational requirements. Analysis of known solutions proves that for modern monitoring of technical condition new means of diagnostics and forecasting are in demand, namely - fiber optic devices insensitive to most operational destabilizing factors (DF). That is why the scientific task of creating diagnostic tools that function in difficult operating conditions and are adapted for continuous, long-term and reliable monitoring of the condition of architectural structures under the action of concentrated influence of DF is relevant and in demand by construction companies, the solution and practical use of which significantly increases the level of safety of super-tall buildings.

To overcome a certain restraint in the improvement of measuring equipment, a direction of development of measuring transducers based on the use of optical radiation for recording physical effects has been formed. The use of unique properties of optical materials is an effective solution for the creation of fiber-optic measuring transducers (FOMT) and IMS communication lines. Technological breakthrough in the production of special optical glass has allowed it to largely surpass the properties of known materials (Fig. 2).

From the standpoint of metrological capabilities, FOMT not only equaled traditional measuring instruments, but also surpassed them in many respects (Table 1).

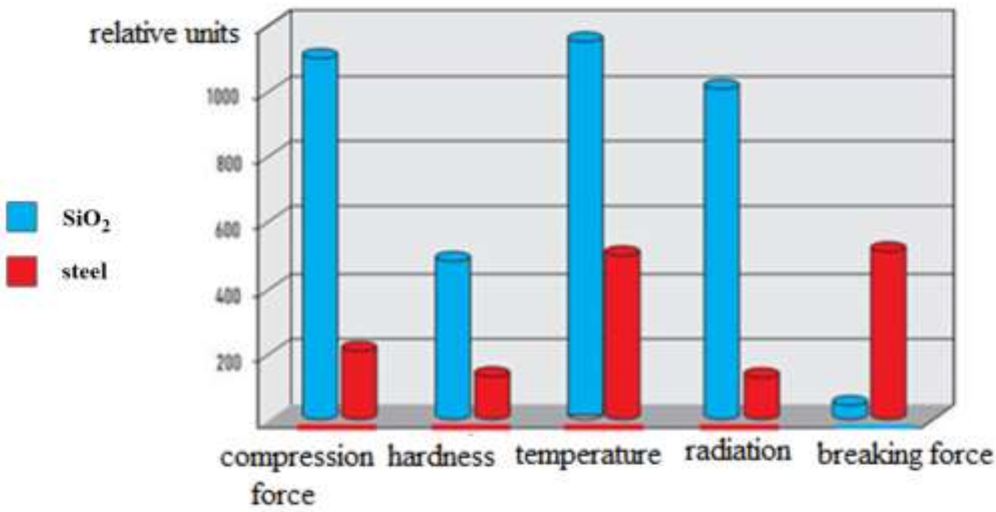


Fig. 2. Comparison of the properties of quartz glass and stainless steel as a material for creating meters

Table 1 – Measurement limits of various physical quantities by traditional and FOMT

Physical quantity	Unit of measurement	Measurement limit of traditional sensors	The limits of FOMT measurements have been reached	Limit of measurement of FOMT
Deformation	M	10^{-4}	10^{-12}	10^{-14}
Pressure	Pa	$7{\cdot}10^{-4}$	10^{-4}	10^{-6}
Temperature	°C	10^{-4}	10^{-6}	10^{-8}
Rotation	$rad{\cdot}s^{-1}$	10^{-4}	10^{-4}	10^{-8}
Acceleration	m/s^2	10^{-6}	10^{-4}	10^{-8}

FOMT are potentially insensitive to external electromagnetic fields, are characterized by small weight and dimensions, simple circuit solutions, high reliability, resistance to operational factors, chemical inertness, and have complete optical galvanic isolation from electronic equipment. Converters of this class have high mechanical strength, high speed, and long service life. There are known samples of FOMT that successfully function at temperatures up to 1170 K.

A significant advantage of FOMT over traditional types of measuring devices is due to free connection with fiber-optic information transmission lines and the ability to organize distributed measuring systems with a significant number of sensors and a single optical channel (OC). The organization of fiber IMS, with the ability to multiplex optical signals, allows solving the problem of reducing the mass and nomenclature of ship measuring instruments and cable networks. In addition, the cost of basic fiber-optic components is rapidly decreasing, while quality and reliability are increasing. It is predicted that by 2025, due to the reduction in production costs, it will be possible to use fiber-optic devices more widely in the control processes of monitoring the condition of systems and equipment of complex power equipment (Fig. 3).

The classification of amplitude FOMTs based on the concept of "optical channel" allows to a large extent to unify and standardize the schemes of converters and divide them into three classes.

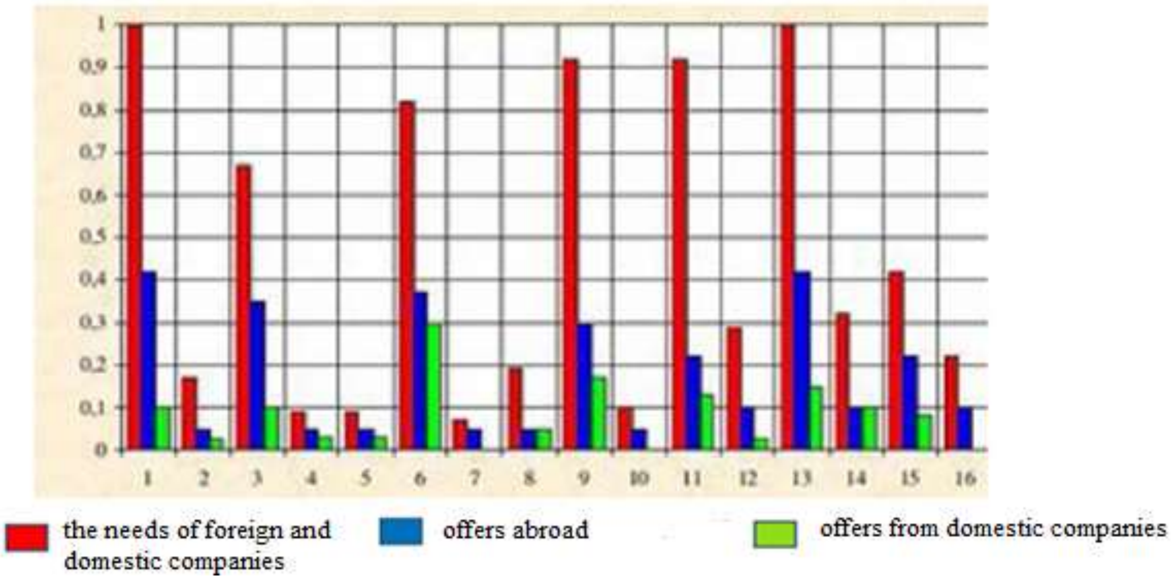
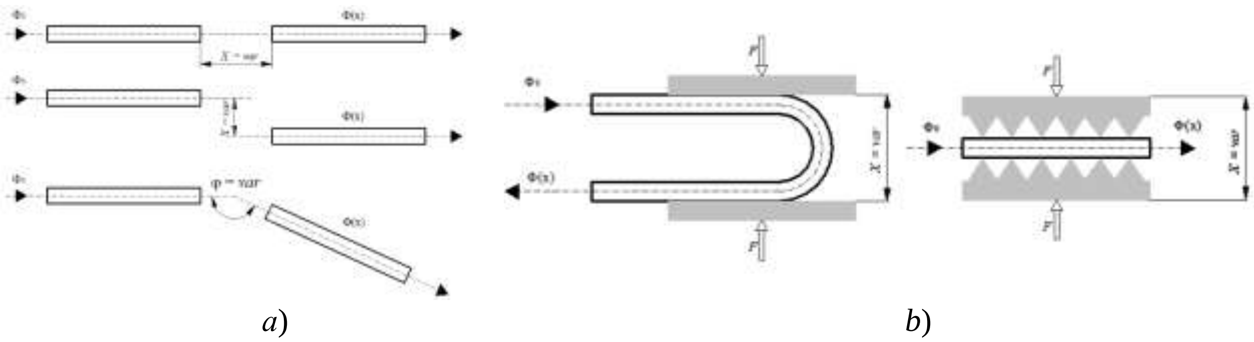


Fig. 3. The ratio of demand and supply for FOMT: 1 – displacement; 2 – speed; 3 – acceleration; 4 – deformation; 5 – coordinates; 6 – rotation frequency; 7 – torque; 8 – TZP drift; 9 – level; 10 – flow rate; 11 – pressure; 12 – force; 13 – temperature; 14 – presence of flame; 15 – gas composition; 16 – magnetic field strength

In FOMTs of the first class (with an open optical channel), changes in the measured physical quantity cause changes in the conditions of light propagation in the gap of the optical fiber in the measurement zone. These include converters of the transmission, reflection, attenuator, nephelometric types and converters with violation of the condition of total internal reflection (TIR).

In FOMTs of the second class (with a closed optical channel), changes in the physical quantity cause changes in the conditions of light propagation in the optical channel in the measurement zone. In this case, changes in the geometric or physical parameters of the fiber under the action of the measured physical quantity lead to changes in the radiation intensity in the optical fiber.

These include converters of the bending, microbending, refractometric and absorbing types. In the FOMT of the third class, changes in the measured physical quantity cause changes in the radiation parameters of light-generating substances located in the measurement zone. These converters belong to the class "without an external radiation source". As can be seen (Fig. 4, *a, b*), the open end surfaces and fiber surfaces in contact with the deforming elements of the converter are subjected to destructive effects during operation.



a) *b*)

Fig. 4. Generalized schemes of FOMTs of amplitude modulation with: *a* - open optical channel; *b* - closed optical channel

Factors contributing to the destruction of optical fiber (OF) include the influence of moisture, acidic and alkaline environments, and mechanical effects on the surface (Fig. 5).

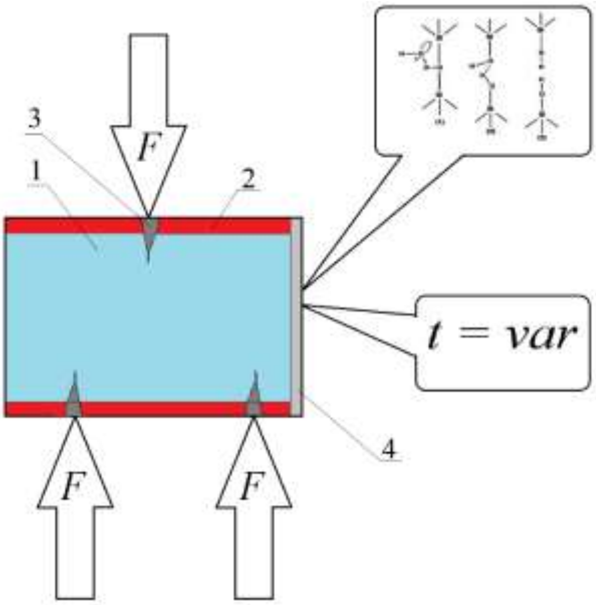


Fig. 5. Factors affecting the parameters of an optical fiber

The quality of the end surfaces of optical fibers affects the parameters and characteristics of radiation in FOMT. In addition to mechanical damage to the surfaces, which leads to the appearance of scratches and surface roughness, there are other mechanisms for the formation of inhomogeneities. These include, in particular, surface contamination, penetration and condensation of moisture on the surface of optical fibers during sharp temperature changes, and destruction of surfaces under mechanical influence.

The process of destruction of glass materials under the influence of moisture and high temperatures is caused by stimulated hydrolysis. In this case, a water molecule is built into the strained *Si-O-Si* bond in several stages and breaks it, closing new bonds with hydrogen. This process occurs in the surface layer of glass.

For open glass surfaces, the bridging bond between silicon ions is broken, and two differently charged unstable "radicals" are formed. These "radicals" demonstrate greater reactivity to molecules of the environment in which they are located, especially H_2O. This means that in both cases the silicon atom combines with the *OH* group, forming the *Si-OH* - silanol group. Silanol groups are chemically reactive: the hydrogen ion H moves relatively easily and can be replaced by other compounds. Other oxides and, under certain conditions, entire layers can appear on the glass surface in this way. Then water molecules are adsorbed, and a state of equilibrium with water vapor in the surrounding atmosphere is formed. The chemically bound layer of water has a thickness of 10^{-10} cm and is called the "permanent hydrated surface layer".

The mechanisms of aqueous (hydrolytic) and acid corrosion are very similar: in both cases, there is an effect on cations - modifiers, especially on reactive alkali ions.

While hydrolytic and acid corrosion in ordinary glass is insignificant, alkaline solutions strongly corrode almost all glasses, dissolving even their mesh. The intensity of corrosion increases exponentially with the concentration of alkali and with temperature.

After the reaction with the alkalis on the surface is completed, the interaction is transferred to the layers below, overcoming the barrier of the silicate lattice, and, therefore, the further process is diffusion. This process occurs more intensively, the greater the amount of alkalis contained in the glass and the higher the ambient temperature.

The layer formed during the reactions gradually thickens. Accordingly, the porosity and surface area increase. Such a surface is able to adsorb water physically as a result of the action of capillary forces, and the leached surface layers swell, forming a layer of silica gel up to 100 ... 200 nm thick. With further growth in the thickness and porosity of the leached layer, leaching can pass into the deeper layers, which will cause gradual destruction of the optical fiber.

In the presence of very little water, the course of the reactions changes significantly. The initial hydrolytic interaction with pure water turns into an alkaline one, which intensifies with increasing temperature. When the transition to alkaline action occurs, the silica framework breaks down, and a destroyed layer forms on the glass surface.

It is obvious that the formation of permanent destructured surface layers initiates a change in the roughness of the end optical surfaces. The study of this process has shown that increasing the degree of roughness of the surface of the input end of the optical fiber leads to a change in the input efficiency and mode composition of the radiation (Fig. 6).

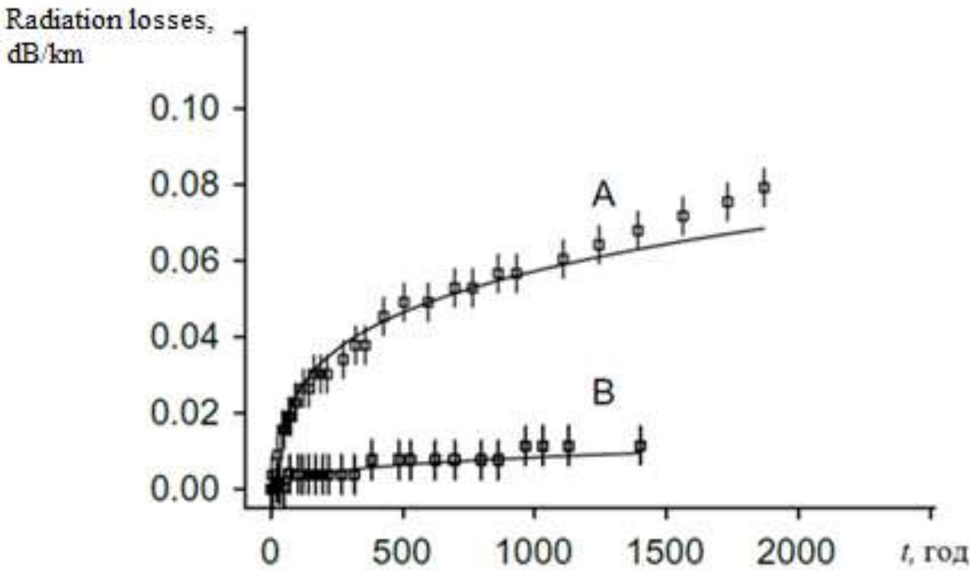


Fig. 6. Effect of alkali on losses due to hydrogen aging for optical fiber with alkaline contamination:
A – 1,35 *ppma NA+Li*; B – < 0,3 *ppma*

It is obvious that the formation of stable destructured surface layers initiates a change in the roughness of the optical end surfaces. Increasing the degree of roughness of the surface of the input end of the optical fiber leads to a change in the input efficiency and mode composition of the radiation.

The results of experimental studies and calculations of the equivalent aperture input and input efficiency for different types of fibers with different degrees of end roughness at a wavelength of 0.63 μm are shown in Fig. 7.

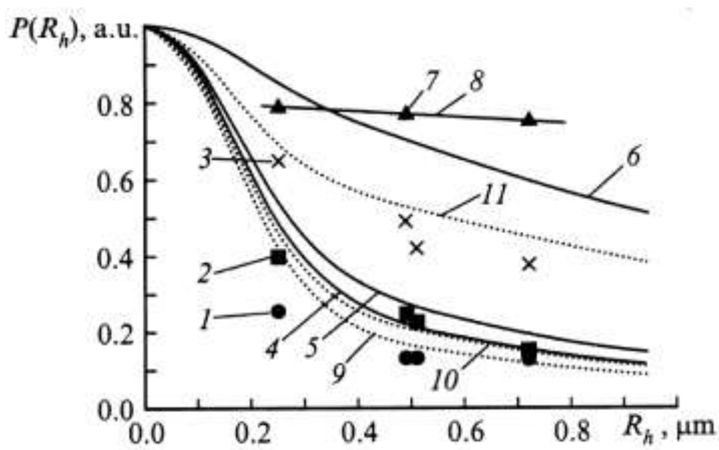


Fig. 7. Dependence of the input efficiency as a function of the root-mean-square roughness height *Rh* for different fibers: 1-3 – experiment; 4-6 – calculations; 7 – coefficient *ks* (experiment); 8 – linear approximation of *ks*; 9 -11 – calculations; 1, 4, 9 – fibers with a stepped refractive index profile (*RIP*), core radius a = 100 μm, aperture angle at the level 1/*e*, y_c = 4.34°; 2, 5, 10 - gradient fibers 50/125, a = 25 μm, γ = 5°; 3, 6, 11 – "quartz-polymer", a = 100 μm, γ = 12.4°

Thus, when light is scattered on the destructured layers formed at the end of the optical waveguide, the excitation of waveguide modes occurs in a wider range of angles of incidence of a plane electromagnetic wave. Diffuse scattering occurs at the input end of the optical waveguide, and scattered radiation enters the angular aperture at angles of entry γ > γs.

Thus, the input characteristic of an optical waveguide with a destructured layer at the end is equivalent to the similar characteristic of an optical waveguide with an end that has no scattering, but has a larger aperture angle γ^* and lower efficiency.

When the lateral surface of the fiber interacts with the deforming elements of the measuring transducer, under the influence of DF, the process of destruction of the optical waveguide proceeds in two stages.

At the first stage, a change in the controlled physical quantity initiates contact between the deformers and the side surface of the optical waveguide. The interaction occurs not over the entire surface, but over a smaller contact surface, caused by microscopic irregularities on the surfaces of both elements.

For the spectrum of the light intensity vector $\boldsymbol{I_0}$ of the axis propagating in the direction of the *z*-axis, local microscopic inhomogeneities of the waveguide surface are equivalent to spatial fluctuations (n of the effective refractive index $n(r)$ relative to its average level nav. The roughness of the optical waveguide surface generates a distributed coupling over the deformed section of the optical waveguide between the spectrum of excited waveguide modes (*EWM*) and a constant and multiple energy exchange between the components of the input signal vector $y(z, t)$ (Fig. 8).

The energy exchange between *EWM*, radiative modes and parasitic modes, in the presence of waveguide surface roughness, causes an increase in radiation losses.

It is established that the value of the radiation loss coefficient, taking into account the discrete nature of the energy spectrum of roughness, can be estimated as

$$\alpha_m = \sum_i \int_0^{\pi} \alpha_i \ (\vartheta^* \beta^*) \frac{\partial K_0(\vartheta^*)}{\partial \vartheta} \alpha + \sum_i \int_{\frac{\pi}{2}-\Theta}^{\frac{\pi}{2}+\Theta} \alpha_i \ (\vartheta^* \beta^*) \frac{\partial K_0(\vartheta^*)}{\partial \vartheta} i,$$

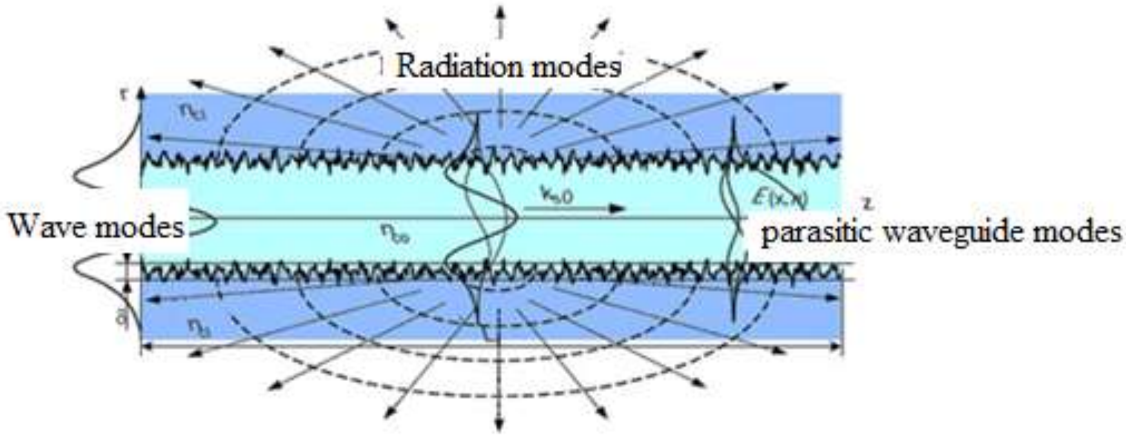
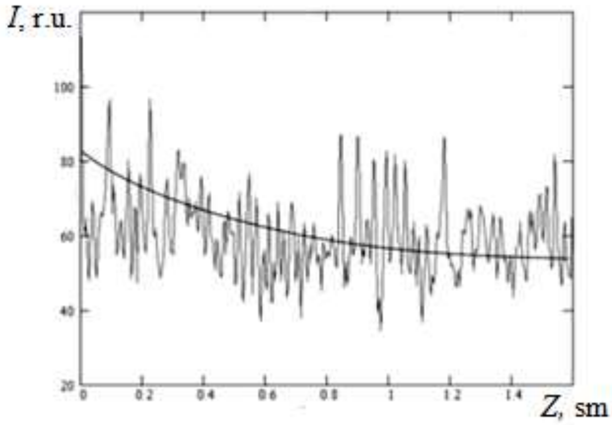


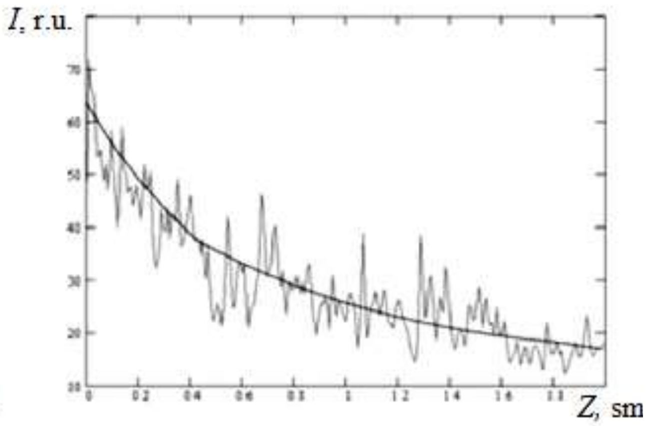
Fig. 8. Transformation of the mode spectrum in an optical waveguide on a rough surface

where K_0 is the component of the energy spectrum $G(K)$ that satisfies the synchronization condition; $\upsilon*$, $\beta*$ are the sliding angles of the *VM* and *PCM* relative to the normal to the optical waveguide; i is the summation index over harmonics of the discrete roughness energy spectrum; Θ is the critical angle of light radiation introduction into the waveguide.

As a result, the light introduced into the optical waveguide undergoes scattering by the surface roughness during propagation and is emitted into the environment. Fig. 9 *a, b* show the distributions of the scattering intensity of radiation for two optical waveguides with surfaces having different roughness.



a)



b)

Fig. 9. Distribution of track intensity along the direction of wave propagation (z):
a – attenuation coefficient $\alpha \approx 0.3$ cm^{-1}; b – $\alpha \approx 0.6$ cm^{-1}

Thus, conditions are created for parasitic modulation of the information signal and deterioration of the metrological characteristics of the measuring transducer. In the second stage, microcracks are formed on the surface of the optical waveguide in places of local contacts, which determine the mechanical strength of the optical waveguide material.

At the tips of these cracks are the strained *Si-O-Si* bonds. Moisture from the environment penetrates through the polymer shell and, in the presence of a strained bond, initiates the process of crack growth in the form of thermomechanically stimulated hydrolysis, the duration of which is defined as

$$\tau = \tau_o C^{-\alpha} exp((U - K\sigma)/RT),$$

where τ – duration of the destruction process; τ_o – period of atomic vibrations (10^{-13} s); α – order of hydrolysis reaction; K – constant characterizing the defectivity of the sample; C – relative humidity; U – activation energy of hydrolytic cleavage of the Si-O bond; R – gas constant; T – temperature; σ – voltage.

After taking the logarithm of the previous equation and taking into account the equality of the order of the hydrolysis reaction of the unit

$$ln\tau = ln\tau_o - lnP_{H2O} + lnP^o_{H2O} + ((U - K\sigma)/RT),$$

where P_{H2O} – water vapor pressure; P^o_{H2O} – saturated water vapor pressure, which depends on temperature.

From the last equation it follows that at P_{H2O} equal to 0, $ln\tau$ is equal to infinity, which is not true. Therefore, it is obvious that there is a limit level of P_{H2O}, further reduction of which does not lead to an increase in the strength of the fiber. In this case, the mechanohydrolytic process of destruction of the optical fiber is transformed into a thermofluctuation process. The nature of the change in the strength of the optical waveguide under the influence of the mechanohydrolytic and thermofluctuation processes of destruction is presented in Fig. 10.

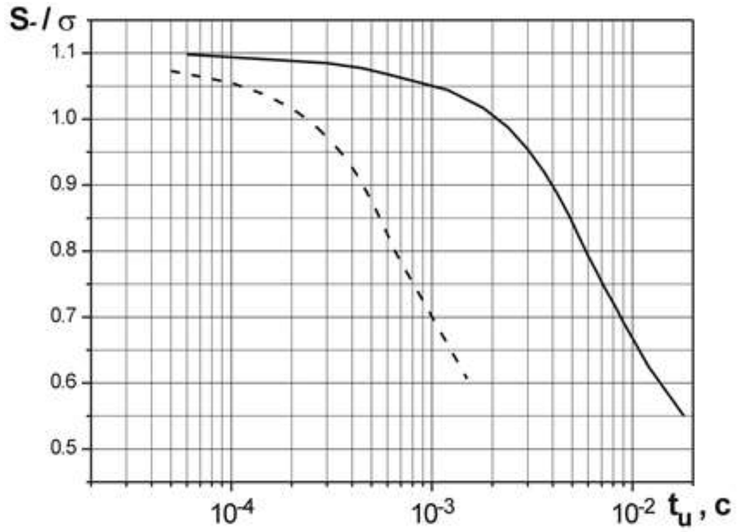


Fig. 10. Results of calculations of the minimum inert strength σ after the control test from the unloading time when taking into account the influence of diffusion-limited regions and thermal fluctuation crack growth for an optical waveguide with scratches or fused particles in the protective polymer coating (solid line), as well as for indented optical fibers without coating (dashed line)

At the same time, fiber-optic sensors with an open optical channel have a number of other disadvantages: they have low conversion sensitivity, non-optimized design due to difficulties in mathematical description of the model, low resistance of the optical system to changes in design parameters, which significantly reduces the metrological characteristics of the IMS.

Based on the analysis of the processes of destruction of glass materials under the influence of physical and mechanical factors, the following conclusions were made: transducers with a closed optical channel are least affected; when the sensitive element is deformed, its lateral side should be avoided [4, 5].

Presentation of the research material with the rationale for the obtained scientific results. A known device is a device for bending structural elements, which contains a laser emitter with a visible beam, reflectors attached to the surfaces of the element, a device for suppressing the side and rear backgrounds, and a light detector for registering deviations of the laser beam, which consists of a photodetector, an electrical signal amplifier, an information recording and processing unit, and a device connected to it for determining the coordinates of the surfaces [6].

The disadvantages of this device are:

- the complexity of the design, which contains a light receiver from several series-connected devices, the total error of which affects the accuracy of measurements;
- the small range of measurement of angular displacements of the blades, which is limited by the dimensions of the lens of the photodetector of optical signals;
- the use of paint, films and paper as reflectors sharply reduces the intensity of the reflected beam due to its absorption and scattering, which requires additional means for suppressing the side and rear backgrounds, which are close in intensity to the reflected beam;
- the need to use several laser emitters if it is necessary to determine the positions of a number of elements.

The closest in technical essence and achieved result to the proposed utility model is a similar device for determining angular displacements of surfaces, which contains a unit for recording and processing information, a laser emitter with a visible beam, reflectors attached to the surfaces of the blades, a light detector for recording beam deflection and a photodetector. A screen with a measuring scale along two coordinate axes is used as a light detector [7].

The disadvantages of this device are:

- the need for periodic geometry adjustment and cleaning of the surfaces of the open optical channel, which consists of two separate elements, such as a reflector and a screen;
- the need for precision accuracy when mounting the device on the blade; - the influence of hydrometeorological and operational factors on the reliability of measurements.

The technical task is to create a device for determining angular displacements of surfaces, which eliminates the disadvantages of an open optical measurement channel, dependence on hydrometeorological and operational factors, increases the reliability of measurements, and at the same time preserves the reliability and simplicity of circuit solutions of known types of devices.

The problem is solved by the fact that the device for determining angular displacements, which contains a unit for recording and processing information, a laser emitter, a photodetector. The main difference is that the laser emitter and the compensating interferometer, associated with the photodetector, are connected to the primary branches of a two-way optical splitter, the secondary branches of which contain optical filters and are connected to planar light guides, which contain fiber Bragg gratings and are fixed along the internal space of the structural element parallel to and perpendicular to the working plane.

The technical solution is explained by the drawing, which shows a device for determining the angular displacements of the blades, which consists of a laser emitter 2, which is connected to one of the primary branches of a two-way optical splitter 3 for transmitting radiation in the forward direction (Fig. 11).

The secondary branches of the double-sided optical splitter, which contain optical filters 4, are connected to two planar optical fibers 5. The planar optical fibers contain fiber Bragg gratings 6 and are rigidly fixed in the internal space of the blade 1 in planes parallel and perpendicular to the plane of rotation of the blade. The second primary branch of the double-sided optical splitter is connected to a compensating interferometer 7, which perceives radiation in the reverse direction, which is reflected from the ends of the planar optical fibers. The radiation, after conversion in the compensating interferometer, is fed to the photodetector 8 and the information registration and processing unit 9.

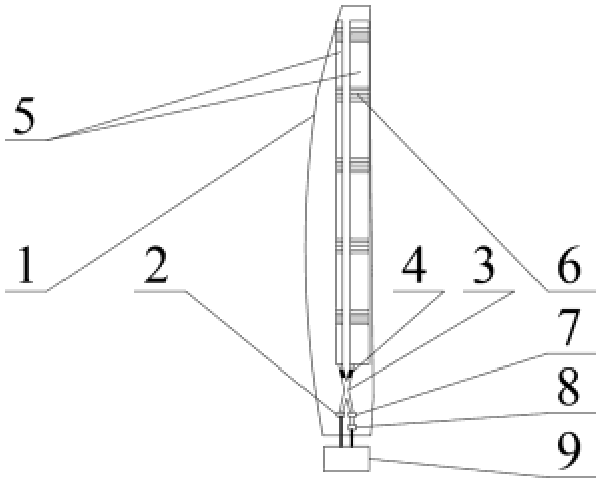


Fig. 11. Device for determining angular displacements: 1 – structural element; 2 – laser emitter; 3 – two-way optical splitter; 4 – optical filter; 5 – planar optical fibers; 6 – fiber Bragg grating; 7 – compensating interferometer; 8 – photodetector; 9 – information registration and processing unit

The device works as follows: The radiation from the laser emitter is directed to the primary branch of a two-way optical splitter [7, 8].

In the splitter, the radiation is divided into two streams, and in the optical filters in the secondary branches, the wavelength of the radiation is converted for each planar fiber individually. The converted radiation is introduced into the planar fiber with fiber Bragg gratings. The section of the planar fiber between the two fiber Bragg gratings is a Fabry-Perot interferometer.

The planar optical fibers are rigidly connected to the working surface, so that the deformation leads to stretching or compression of the planar optical fibers. Under the influence of deformation during bending, the phase difference of the signals from two adjacent fiber Bragg gratings changes. Each of the fiber Bragg gratings reflects the pulse arriving at it from the laser emitter at the same Bragg wavelength. In this case, the time delay between the reflected pulses is equal to twice the propagation time of light in the sensitive element of the sensor - the planar optical fiber between the gratings.

The radiation reflected from the ends of the planar light guides enters the compensating interferometer. The change in time of the deformation of the planar light guides as a result of external influence causes a change in the phase difference of the interfering pulses. The latter is converted by the photodetector into a change in the current value. The additional phase shift between the interfering pulses ensures the operation of the photodetector in the area of maximum steepness, and the equality of the intensities of the interfering pulses allows to obtain the maximum amplitude of the signal at the output of the photodetector [9 - 11].

Conclusions and prospects for further research. The device is simple to manufacture and use, because it uses fiber-optic components mastered by industry.

The technical result is achieved due to the fact that the use of planar optical fibers with fiber Bragg gratings fixed along the internal space of the structural element parallel and perpendicular to the working plane will ensure:

- simultaneous measurement of bending in two planes;
- stability of the parameters of the monoblock sensitive element of the sensor in the form of planar optical fibers;
- invariance to the influence of hydrometeorological and operational factors on the measuring channel;
- increased measurement reliability;
- reduction of costs for maintenance of the device in operation.

The proposed measuring device, in addition to its potential application not only in the general architectural sense, can also contribute to the development of narrowly professional fields of application of new ideas for monitoring building structures. As well as promote more effective cooperation between stakeholders and higher education institutions [12 -14].

References

[1] Makeyev, A. V., Mareyev, A. V. Obzor optovolokonnykh datchikov i sistem monitoringa deformatsiy sooruzheniy. URL: https://www.researchgate.net/ publication/ 37698 9769_Obzor_optovolokonnyh_datcikov_i_sistem_monitoringa _deformacij_sooruzenij

[2] Tyurikova, O. M., Sandler A. K. Arkhitekturno-tekhnolohichni zasoby zakhystu ekipazhiv mors′kykh suden // The current state of development of world science: characteristics and features: collection of scientific papers "SCIENTIA" with Proceedings of the VII International Scientific and Theoretical Conference, June 14, 2024. Lisbon, Portuguese Republic: International Center of Scientific Research. P. 123 - 126. DOI https://doi.org/10.36074/ scientia-14.06.2024.

[3] Goncharenko, I. A., Ivanitskiy, A. G., Ryabtsev, V. N. Volokonno-opticheskiy datchik dlya monitoringa sostoyaniya nesushchikh konstruktsiy vysotnykh zdaniy. URL: https://rep.bntu.by/ bitstream /handle/data/14791/66-67.pdf?sequence=1&isAllowed=y

[4] Sandler, A. K. Metod pidvyshchennya efektyvnosti diahnostuvannya tekhnichnoho stanu sudnovykh hazoturbinnykh ustanovok na osnovi volokonno-optychnykh tekhnolohiy: dys. ... kand. tekhn. nauk: 05.22.20. – K., 2021. – 159 s.

[5] Sandler, A. K. Informatsiyno-vymiryuval′ni prystroyi na osnovi volokonno-optychnykh tekhnolohiy. – Odesa: Vydatinform NU"OMA", 2018. – 165 s.

[6] Patent № 38950. MPK G01P 3/36. Ustroystvo dlya identifikatsii bystrodvizhushchikhsya ob"yektov, preimushchestvenno lopastey nesushchego vinta vertoleta / zayavitel' i patentoobladatel' Kuznetsov A. M. – 2004102413. – zayavl. 28.01.2004; opubl. 10.07.2004. – 3 s.

[7] Patent № 123028. MPK G01P 3/44 (2006.01) G01B 7/30 (2006.01) B64C 11/16 (2006.01). Prylad dlya vyznachennya kutovykh peremishchen′ lopatey / H. O. Obors′kyy, B. O. Morhun, YU. B. Morhun, I. V. Prokopovych; zayavnyk ta volodar patentu Odes′kyy natsional′nyy politekhnichnyy universytet. – u201707245. – zayavl. 10.07.2017; opubl. 12.02.2018, Byul. № 3. – 3 s.

[8] Patent № 155948. MPK G01M 11/02 (2006/01). Volokonno-optychnyy datchyk akroleyina / A. K. Sandler, YU. I. Zhuravl′ov; zayavnyk ta volodar patentu Natsional′nyy universytet "Odes′ka mors′ka akademiya". – u202305883. – zayavl. 06.12.2023; opubl. 17.04.2024, byul. № 16/2024. – 3 s.

[9] Sandler, A., Budashko, V., Khniunin, S., Bogach, V. Improving the mathematical model of a fiber-optic inclinometer for vibration diagnostics of elements in the propulsion system with sliding bearings // Eastern-European Journal of Enterprise Technologies. Applied physics. – 2023. – Vol. 5. – №. 5(125). – P. 24 – 31. DOI: 10.15587/1729-4061. 2023. 289773.

[10] Sandler, A. K. Chuvstvytel′nyy élement volokonno-optycheskoho akselerometra na osnove sapfyrovoho stekla // IX mizhnarodna naukovo-metodychna konferentsiya "Sudnova elektroinzheneriya, elektronika i avtomatyka", 05-06 lystopada 2019 r.: materialy konferentsiyi. – Odesa: NU "OMA". – 2019. – S. 27 - 33. dx.doi.org/10.31653/2706-7874.

[11] Sandler, A. K., Karpilov, A. YU. Primeneniye volokonno-opticheskikh datchikov v sistemakh avtomaticheskogo diagnostirovaniya sudovykh gazoturbinnykh ustanovok // Avtomatizatsíya tekhnologíchnikh i bíznes-protsesív. – 2019. – T. 11. – № 2. – Odessa: ONAKHT. – S. 46 – 52. DOI https://doi.org/ 10.15673/atbp.v11i2.1374.
[12] Babachenko, M. V., Sandler, A. K. Pidvyshchennya efektyvnosti vzayemodiyi steykkholderiv ta mors′kykh zakladiv vyshchoyi osvity // Education and science of today: intersectoral issues and development of sciences: Collection of scientific papers "LÓHOS" with Proceedings of the VI International Scientific and Practical Conference, Cambridge, March 29, 2024. Cambridge-Vinnytsia: P.C. Publishing House & UKRLOGOS Group LLC. – 2024. – R. 82 - 84. DOI 10.36074/logos-29.03.2024.019.
[13] Sandler, A. K., Omel′chenko, T. YU. Pro neobkhidnist′ vprovadzhennya novitnikh tekhnolohiy monitorynhu tekhnichnoho stanu bezpilotnykh suden // Ricerche scientifiche e metodi della loro realizzazione: esperienza mondiale e realtà domestiche: Raccolta di articoli scientifici "ΛΌГОΣ" congli atti della V Conferenza scientifica e pratica internazionale, Bologna, 26 aprile, 2024. Bologna-Vinnytsia: Associazione Italiana di Storia Urbana & UKRLOGOS Group LLC, 2024. – P. 240 - 244. DOI 10.36074/logos-26.04.2024.049.
[14] Tyurikova, O. M., Sandler, A. K., Zavarza, I. O. Formuvannya napryamkiv avtomatyzovanoho proektuvannya inter'yernykh rishen′ hromads′kykh prostoriv suden dlya transportuvannya zernovykh kul′tur // Automation of Technological and Business Processes. – 2024. – № 16 (3). – P. 84 - 94. DOI: https://doi.org/10.15673/atbp.v16i3.2878.

ВОЛОКОННО-ОПТИЧНЕ ОБЛАДНАННЯ ДЛЯ ТЕХНІЧНОГО ДІАГНОСТУВАННЯ ВИСОТНИХ АРХІТЕКТУРНИХ СПОРУД

[1]Сандлер А.
sa@onma.edu.ua, ORCID: 0000-0002-0709-0542
Національний університет «Одеська морська академія»
вул. Дідріхсона, 8, Одеса, 65052, Україна

Анотація. Проблема забезпечення надійного сприйняття несучими будівельними конструкціями розрахункових навантажень після негативного впливу гідрометеорологічних або руйнівних експлуатаційних факторів особливо гостро постає зі збільшенням поверховості архітектурних споруд. Це завдання обов'язково враховується на етапі проектування. Проте в розрахунках не можна врахувати фактичний стан несучої конструкції будівлі після землетрусу, бурі чи пожежі. Сучасне поняття «експлуатація до попереднього стану» базується на різних методах прогнозування технічного стану, зокрема – виявлення руйнувань на початковій стадії їх розвитку. Практичне використання цієї концепції вимагає впровадження нових, більш ефективних, зручних у використанні, автоматизованих засобів і пристроїв технічної діагностики та прогнозування технічного стану будівельних елементів і конструкцій і значно ускладнює процедури моніторингу. Тенденції розвитку сучасних методів експлуатації свідчать, що саме використання надійних, перевірених, малочутливих до збурень діагностичних засобів і пристроїв, органічно вбудованих в автоматизовану систему управління, забезпечує високу ефективність роботи та надійність функціонування архітектурних споруд. Існуючі засоби та прилади діагностики технічного стану архітектурних споруд працюють в умовах концентрованого впливу дестабілізуючих факторів. Саме ці збурення не дозволяють ефективно діагностувати та прогнозувати технічний стан архітектурних споруд, які відповідають сучасним вимогам експлуатації. Аналіз відомих рішень доводить, що для сучасного моніторингу технічного стану затребувані нові засоби діагностики та прогнозування, а саме - волоконно-оптичні пристрої, нечутливі до більшості експлуатаційних дестабілізуючих факторів. Тому актуальною та затребуваною будівельними компаніями є наукова задача створення діагностичних засобів, що функціонують у складних умовах експлуатації та пристосованих для безперервного, тривалого та достовірного моніторингу стану архітектурних конструкцій під дією концентрованого впливу дестабілізуючих факторів, вирішення та практичне використання яких значно підвищує рівень безпеки надвисоких будівель. Для подолання певної стриманості у вдосконаленні засобів вимірювальної техніки сформувався напрям розвитку вимірювальних перетворювачів, заснований на використанні оптичного випромінювання для реєстрації фізичних ефектів. Використання унікальних властивостей оптичних матеріалів є ефективним рішенням для створення волоконно-оптичних вимірювальних перетворювачів і ліній зв'язку інформаційно-вимірювальних систем. Технологічний прорив у виробництві спеціального оптичного скла дозволив йому значно перевершити властивості відомих матеріалів. Поставлена задача вирішується створенням пристрою для визначення кутових переміщень, який містить блок запису та обробки інформації, лазерний випромінювач, фотоприймач і який відрізняється тим, що лазерний випромінювач і компенсуючий інтерферометр, з'єднаний з фотоприймачем, з'єднані з первинними гілками двостороннього оптичного розгалужувача, вторинні гілки якого містять оптичні фільтри і з'єднані з плоскими світловодами, які містять волокнисті бреггівські решітки. і закріплені вздовж внутрішнього простору елемента будівлі паралельно і перпендикулярно до його площин.

Ключові слова: надвисока будівля, технічний моніторинг, волоконно-оптичний датчик