ABSTRACT

dissertation work on the topic:

"**Research and modelling of the functionality of fiber-optic multifunctional sensors for monitoring technological processes**", submitted for the Doctor of Philosophy (PhD) competition in the specialty "8D06201 - Telecommunication"

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Assessment of the current state of the scientific and technological problem (task) being solved.

For decades, electrical sensors (strain-resistive, string, potentiometric, etc.) have been the main way to measure physical and mechanical phenomena. Despite their widespread use, electrical sensors have a number of disadvantages, such as: signal transmission losses, susceptibility to electromagnetic interference, the need for an intrinsically safe electrical circuit (if there is a risk of explosion). These inherent limitations make electrical sensors unsuitable or difficult to use in a number of applications. The use of fiber optic sensors is an excellent solution to these problems. In fiber optic sensors, the signal is light in the optical fiber, instead of electricity in the copper wire of traditional electrical sensors.

Over the past twenty years, a huge amount of innovation in optoelectronics and in the field of fiber optic telecommunications has led to a significant reduction in the price of optical components and a significant improvement in their quality. This allowed fiber-optic sensors to move from the category of experimental laboratory devices to the category of widely used devices in such areas as monitoring buildings and structures, etc.

A significant contribution to the development, development of the theoretical foundations, elements and mechanisms for designing a fiber optic sensor (FOS) was made by such Russian and foreign scientists as V.M. Busurin, M.M. Butusov, V.D. Burkov, A.V. Gorish, Yu.A. Gulyaev, Ya.V. Malkov, T.I. Murashkina, V.T. Potapov, Okoshi T., Okamato K., Otsu M and others.

Modern fiber optic sensors have the following properties:

- can be used in an explosive environment due to absolute explosion safety;
- have high mechanical strength, small dimensions, simple design and, accordingly, high reliability;
- chemically inert;
- are made of dielectric materials, which ensures the absence of paths for the passage of electric current through them;
- have high resistance to elevated temperatures, mechanical shocks, vibrations and other environmental influences;
- allow to make non-contact and remote measurements.

Some VOS can be used in situations in which electronic devices either cannot be used at all, or such use is accompanied by significant difficulties and costs (for example, temperature measurement in high-voltage electrical equipment such as alternators, transformers; current and voltage measurement in high-voltage

power lines ; fast temperature measurement of small surfaces with low thermal conductivity and variable reflectivity, in hard-to-reach places).

The elements used in fiber optic sensors are completely passive to electricity, which makes them suitable for various industries such as space industry, mining, oil industry, pipeline monitoring, etc.

The practice of measurements in the space industry shows that of all the measured parameters in engineering, industry and technology, deformation is (20–30)% and temperature (10–20)% of all measurements. At the same time, temperature is often only an indirect parameter used in the main measurements of other parameters.

Thus, the total measurement of deformations and temperature accounts for about 35-45% of measurements, so the creation of measuring transducers (MT) that simultaneously measure deformations and temperature (as a multifunctional sensor) in extreme operating conditions is a very relevant topic.

This topic is mainly dealt with by foreign companies and research teams and scientists, including such as P.J. Lemaire, R.M. Atkins (USA), S.V. Varzhel, O. I. Medvedkov, I. G. Korolev (Russia). Unfortunately, Kazakhstan does not have its own production of sensors, so only imported ones are used.

At present, fiber with Bragg gratings (FBG) is considered as one of the most promising sensitive elements of a fiber optic sensor. Fiber-optic Bragg gratings (FBGs) are widely used both in communication systems and as sensors for temperature and deformation of objects. Therefore, a large number of scientific works are devoted to the study of the properties of FBGs. The basic principles of work, the manufacturing technology of VRB are displayed in the works of A. Othonos [1], C. E. Campanella [2], S. A. Vasiliev [3], and possible applications are in the works of S.V. Vargel [4], Kun Yao, Qijing Lin, Zhuangde Jiang, Na Zhao, Bian Tian, Peng Shi and Gang-Ding Peng [5]. Overview of works on the properties of chirped FBGs and their application is given in Daniele Tosi [6].

The use of FBG in industries, in particular, in medicine, is considered in the reviews of works by A. Shadab [7], C. Massaroni [8], D.L. Presti [9]; in biochemistry and pharmacy in the works of A.M. Riza [10], C. Broadway, [11]; for environmental industries in the works of D. Nadeem [12]; as well as for other industries in the works of A.G. Leal-Junior, [13].

Rationale for the need for research work. When developing sensors for the rocket and space industry, under the influence of the main factors that characterize the technical requirements for the development of devices, a difficult task arises to ensure the functioning of the sensors. Sensors used in the space industry are the most affected by external factors. And also due to extreme external temperature, shock, vibration and especially electromagnetic influences, the requirements for the resistance of the metal case, the stability of measurements and the operation of the engine of the first stage of the rocket and spacecraft are high. As a result of the impact of these destabilizing factors, mechanical displacements and metrological changes occur in the metal body of the spacecraft. Therefore, to register the displacement and strain rates of objects from the above effects, in this work, optical methods were used that use optical fibers to obtain a signal that

depends on the magnitude of the displacement of the object. The technologies and designs of the fiber-optic multifunctional for space infrastructure were considered.

Considering all these facts, it is important to study the creation and functionality of combined fiber-optic sensors with high metrological and operational characteristics.

Goal of the work

The aim of the work is to determine high-speed displacement, temperature change of metal surfaces from applied deformations, temperature using a sensitive element of a fiber-optic multifunctional sensor. This will make it possible to determine how much the devices used in the space industry are deformed under the influence of external destabilizing factors and to find the necessary materials and ways to protect against them.

In the process of performing work to solve this goal, based on the novelty of this direction, it is necessary to investigate the theoretical issues of generation and propagation of coherent radiation through optical media, to determine effective ways to change the radiation parameters under the influence of deformation and temperature. In addition, it is necessary to find physically and technologically compatible conversion methods carried out by a single sensor. Based on the results obtained, it is required to investigate FOS capable of converting deformation and temperature into an electrical or digital value.

Work tasks

To achieve the stated goal of the work, it is necessary to solve the following tasks:

- To make a sensitive element of the fiber-optic sensor;
- Carry out load and temperature tests of the WTO to verify the correctness of the selected design and technological solutions;
- Measure high-speed strains using fiber Bragg gratings;
- Develop mathematical models of elements and structures of an optical multifunctional sensor;

Scientific novelty and significance of the work.

In this paper, for the first time, it is proposed to use an experimental setup of a pulsed magnetic field with optical sensors to determine high-speed displacements, temperature changes in metal surfaces, which has not previously been used in other studies. And this is the novelty of this work.

The results of the study are of practical interest for the Republic of Kazakhstan in terms of developing innovative high-tech products that are in demand in the countries of the Eurasian Economic Union and abroad.

The objects of research are multifunctional sensors designed for space infrastructure.

The subject of the study is the theoretical analysis and experimental studies of the creation and operation of MD elements for space infrastructure.

Research Methods and Ethical Issues

Description of the scientific methods used in the work as a justification for the ways to achieve the goals set, justification of the chosen approach:

The work will use the method of generalization, the method of direct measurement, the method of observation and the method of expert assessments. The generalization method will be used to analyze the state and development trends of combined sensors and space systems based on them. With the help of the method of direct measurement, the readings of the FOS will be recorded during their tests on the benches. The method of observation will include the modeling of the elements and structures of the FOS. The method of expert assessments will allow assessing the quality of the design and technological solutions used in the work and choosing the optimal ones.

When creating a FOS, the main areas of scientific and technical research and activities will be: - development of generalized technical requirements for characteristics, materials and components used, based on a specific subject area;

- identification and analysis of the physical principles of compatible transformation of temperature and pressure by one FOS;

- analysis of existing structures and principles of operation of FOS for use in space instrumentation and determination of the basic ones;

- creation of original constructive and technological solutions in the development of FOS.

The rationale for the chosen approach is the traditional procedure for developing instrument-making products, especially for the space industry, which includes mandatory modeling, design and testing according to the developed methods and on certified test equipment.

Critical points, alternative ways to implement the work:

Taking into account the modern technological level, the available element base and the author's scientific background of the performers on the topic of the work, there is confidence in the successful implementation of this work. With a high degree of certainty, it can be argued that the results obtained in the process of implementing this work are highly competitive and in demand. A way to increase the reliability of the results of the functioning of the channels of the FOS is to conduct a factorial experiment, including both separate supply of pressure and heating, and the combined effect of pressure and temperature. The critical points of work are the purchase of a broadband spectrum analyzer and the manufacture of a test bench. To reduce the risk, these stages will be carried out using spectrum analyzer rental and cooperation.

To achieve the reliability of the test results of experimental models of the FOS, tests will be carried out according to standard methods in a certified test center.

The methods used in the Work to ensure compliance with the principles of scientific ethics, i.e. ethical management procedures, in particular, maintaining high standards of intellectual honesty and avoiding the fabrication of scientific data, falsification, plagiarism, false co-authorship, use by individual participants of collective research, data and conclusions obtained in research, without the consent of other participants.

The owners of the intellectual property objects used in the work are the participants in this work, which excludes violations of scientific ethics at the stage

of performing the work and drawing up application documents for scientific work. All scientific results and objects of intellectual property created in the course of this work will be formalized with the participation of their authors.

A detailed procedure and mechanism for conducting research conducted with the participation of people and animals, a description of the compliance of the planned research with the legislation of the Republic of Kazakhstan.

Conditions for registration and division of intellectual property rights to the results of the study.

The objects of intellectual property created within the framework of this work will be protected by innovative patents of the Republic of Kazakhstan and Eurasian patents, as well as articles in publications with a non-zero impact factor and in journals recommended by the Ministry of Education and Science of the Republic of Kazakhstan.

Relevance of the topic.

As practice shows, temperature and force measurements are the most common in science, technology, and production, therefore, the creation of combined, noise-resistant and energy-efficient MDs, which include FOS with BG, is a very important task. The researched FOS will be in demand for the newly developed and modernized space infrastructure, in the polygon infrastructure, as well as for other strategic sectors of the Republic of Kazakhstan. In addition, high-speed deformation of metals is increasingly used in engineering and production. This is explained by the fact that the loading rates of parts of existing and designed machines and mechanisms, and, accordingly, of metal in the process of its processing are very high, and information about the resistance of metals to deformation, ductility and impact strength in a wide range of deformation rates and temperatures necessary for calculations, in sufficient volume is not available. Characterized by high strain rates, high pressures on the surfaces of the metal being processed and significant energies, high-speed deformation provides high productivity, makes it possible to manufacture products of significant dimensions from strong and low-plastic materials, and allows processing metal that is in a state of motion.

In this regard, the study of the behavior of modern structural and building materials under high-speed deformation and destruction is an extremely significant and urgent problem.

The results of this work are of practical interest for Kazakhstan in terms of developing innovative high-tech products that are in demand in the countries of the Eurasian Economic Union and abroad.

Social demand and economic interest in the implementation of the work.

Import substitution, development and mastering of production of high high-tech products for many branches of industry and science are important government tasks. Creation of new qualified jobs in the conditions of small and medium-sized enterprises, which does not require large capital investments and complex expensive equipment.

The impact of the obtained results on the development of science and technology.

In the course of this work, scientific results will be obtained that will find application in other areas, for example, in instrumentation, automation and mechanical engineering. It is planned to protect the results of the work with several patents of the Republic of Kazakhstan, Eurasian patents and publication of articles in publications with a non-zero impact factor, the release of textbooks and monographs.

Expected social and economic effect:

- import substitution, saving public funds for the purchase of imported products;

-increasing the safety of operation and operation of hazardous facilities;

- mastering the production of new innovative products

-creation of laboratory stands for educational institutions and industry on the basis of the developed FOS.

Communication of this work with other research works.

The work was carried out as part of the research work IRN AP08052850 on the topic “Development of structures and technologies for creating small-sized fiber-optic combined pressure and temperature sensors for space infrastructure”, funded by the Ministry of Education and Science of the Republic of Kazakhstan.

Information about the material support of the dissertation.

Two optical light-sensitive fibers with Bragg gratings deposited on them by the phase mask method and an optical spectrum analyzer MS9740B (Japan) were used to obtain the reflection spectrum from the Bragg grating. An experimental device of a pulsed magnetic field was also used. A universal drying oven SNOL 38/350 was used for temperature influence on the optical fiber with a Bragg grating.

The basic laws of optics, analytical geometry were guided in the construction of a mathematical and physical model of the sensitive element of an optical sensor.

Provisions for defense

Hypothesis put forward:

- determination of high-speed displacement, temperature change of the metal surfaces of the spacecraft (RST) using optical Bragg gratings of the optical multifunctional sensor.

On the basis of the hypothesis put forward, the provisions submitted for defense have been developed:

- methods using optical fibers to obtain a signal that depends on the magnitude of the displacement of the object;

- technologies and designs of a fiber-optic multifunctional sensor;

- mathematical models of elements and structures of the optical multifunctional sensor;

Publications. On the topic of the dissertation, 8 scientific articles were published, including 1 with a non-zero impact factor, 4 articles in scientific publications recommended by the KKSON MES RK.

Approbation of work. The main results of the dissertation work were reported and discussed at the seminars of the department "Radio Engineering,

Electronics and Space Technologies" of KazNRTU named after K.I.Satpayev (Kazakhstan, Almaty); International Conference "Satbayev Readings-2021", Satbayev University, (RK, Almaty, 2021); 2nd international Joldasbekov symposium, Kazakhstan, "Development of a Mathematical Model of Combined Optical Pressure and Temperature Sensors for the Space Industry", (RK, Almaty, 2021) ; ; 2022 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), (Russia, St. Petersburg, 2022) ; EExPolytech-2022: 2022 International Conference on Electrical Engineering and Photonics, (Russia, St. Petersburg, 2022) ;

The structure and scope of the dissertation. The dissertation work consists of an introduction, 4 sections, a conclusion, a list of references. The main text of the work is presented on 125 pages of typewritten text, contains 53 figures, 5 tables, the list of sources used consists of 115 titles.