EURASIAN PHYSICAL TECHNICAL JOURNAL

2024, Volume 21, No. 1 (47)

https://doi.org/10.31489/2024No1/104-113

Received: 16/12/2023 Revised: 23/01/2024 Accepted: 14/03/2024 Published online: 29/03/2024

Original Research Article

UDC 53.082.52

HARDWARE AND SOFTWARE COMPLEX FOR STABILITY CONTROL OF QUARRY SIDES USING OPTICAL FIBER

Madi P.Sh.[1]*, Al'kina A.D.[2], Mekhtiyev A.D.[1], Yurchenko A.V.[3,4]

[1] S. Seifullin Kazakh Agro Technical Research University, Astana, Kazakhstan
[2] Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
[3] Research School of Physics of High-Energy Processes, National Research Tomsk Technical University, Tomsk, Russian Federation
[4] Department of Innovative Technologies, Tomsk State University, Tomsk, Russian Federation
*Corresponding author: peri@mail.ru

Abstract. *This article explores solutions to address the issue of implementing a shift monitoring system in quarries, which is the primary cause of collapsing sides and edges. For guaranteed safety and continuous monitoring of the quarry's activities, advanced fiber-optic sensors have been integrated. Their design is based on the use of single-mode optical fibers, which provides the most accurate assessment of displacements in mountainous terrain up to a distance of 30 km. Extensive laboratory studies have been carried out to deeply analyze the deformation and shear processes occurring in this geographical area. The results obtained from these analyses bode well for a significant improvement in quarry performance and a reduction in the likelihood of emergency situations.*

Keywords: fiber-optic sensor, monitoring system, open-pit mining, quarry, safety, mining, optical fiber, deformation, shear.

1. Introduction

The hardware and software system for controlling the stability of quarry sides using optical fibers is an innovative system designed to monitor and prevent hazardous situations in quarries and open-pit mines. Here are the main components and operating principles of such a system: optical sensors, where optical fibers are placed along the sides of the quarry, as well as inside certain points for direct measurement of displacements in the rock massifs; measuring devices, where special sensors and instruments read data from optical fibers and transmit them for processing; software for data analysis and processing, where the complex includes software algorithms for data processing, their analysis and interpretation; warning system, where the received data are processed and interpreted; and a warning system. When potentially hazardous situations are detected, the system can alert operators to take action to prevent accidents; automated control systems, where in some cases, if serious safety hazards are detected, the system can automatically activate measures to stabilise the pit sides, such as activating drainage systems or changing the mining regime.

The use of a hardware-software complex for monitoring the stability of the quarry sides using optical fiber significantly increases the safety of works, prevents possible accidents and provides continuous control over the condition of the quarry sides. Such systems are becoming increasingly popular in the mining industry, where safety plays a key role, and remain relevant and in demand today. Mining in quarries and open pit mines carries the risk of rockfalls and landslides, which can lead to extremely dangerous situations for workers and have serious environmental consequences. Optical fiber-based technologies offer effective solutions for monitoring the stability of quarry slopes. The advantages of using optical fibers in this context include high accuracy and reliability of signals, resilience and the possibility of remote monitoring. By installing optical fibers on quarry sides and using appropriate hardware and software, displacements in rock masses can be continuously monitored, allowing for the timely identification of potentially hazardous areas and the prevention of accidents. Thus, remains relevant and has great potential for application in the mining and construction industry, as well as for safety and environmental protection.

The purpose of this research is to develop and implement an integrated system for monitoring and controlling the stability of quarry sides using optical fiber.

The main objective is to create a hardware and software system capable of continuously and accurately measuring displacements in rock massifs, as well as warning of possible threats of rockfalls and landslides. Through the integration of optical fibers, sensors and specialised software, we aim to develop an effective system capable of ensuring personnel safety, reducing the risk of accidents and minimising environmental impact in open pit and surface mining environments.

2. Problem statement and literature review

The relevance of the research on the creation of hardware and software complex for controlling the stability of quarry sides using optical fiber is confirmed by several factors:

1. Safety at work, where mining in quarries is associated with the risk of cave-ins and landslides, which can lead to serious accidents and loss of human life. The development of technology to continuously monitor the stability of quarry faces helps to reduce the risk of such accidents.

2. Environmental safety, where rockfalls and landslides in quarries can also cause environmental pollution, which has a negative impact on the environmental conditions in the region. Effective control of the stability of quarry sides helps to prevent such environmental disasters.

3. Production efficiency, where controlling the stability of quarry faces is also important in terms of production efficiency. Preventing rockfalls and landslides avoids temporary production stoppages and equipment damage.

4. Innovation technologies in the mining industry, where the development of new methods for monitoring and controlling the extraction of natural resources is an important area for the modern mining industry. The application of optical fiber to control the stability of quarry sides represents an innovative approach to this problem. Thus, the research in the field of creating a hardware and software system for controlling the stability of pit sides using optical fiber remains relevant and in demand in the modern mining industry, where safety, efficiency and environmental responsibility play a key role.

The novelty of the research in the creation of hardware and software complex for controlling the stability of quarry sides using optical fiber is manifested in several issues.

1. Integration of optical fiber into a monitoring system, where the ability to use optical fiber to monitor the stability of quarry sidings represents an innovative approach. Previous methods may have involved the use of different sensors or transducers, but the use of optical fiber opens up new possibilities for more accurate and continuous monitoring.

2. High accuracy and reliability, where the use of optical fiber achieves high accuracy and reliability in measuring strains and stresses in rock masses. This allows operators to obtain more accurate information on the condition of the quarry faces and take appropriate precautions.

3. Development of specialised software, where specialised software is required to analyse and interpret data obtained from optical fiber. The development of such software includes consideration of the peculiarities of optical monitoring systems operation, signal processing algorithms and visualisation of results. 4. Integration with automated control systems, where the possibility of integrating the data obtained from the monitoring system with automated control systems of the open pit mine allows to promptly respond to detected threats and take measures to prevent emergencies. Thus, the novelty of this study lies in the application of modern optical technologies to create a comprehensive system for monitoring the stability of quarry sides, which leads to increased efficiency and safety in mining.

Open pit mining, compared to underground mining, typically requires less upfront capital investment, provides better access to minerals and has a simpler infrastructure that facilitates more efficient production management. The main issue is always to improve the efficiency of mineral extraction and ensure the safety of personnel during mining operations. It is necessary to strive for full recovery of mineral reserves with minimum stripping works. However, achieving this goal is only possible if the stability of the instrumental rock mass is ensured. This emphasises the importance of developing methods and technologies aimed at ensuring the safety and efficiency of stripping operations at open pits. To solve this issue there are various methods of control, ranging from manual labour up to the use of geotechnical radar and satellite systems of laser scanning, which quite effectively perform the functions of control of the instrument massif of the quarry, but have a number of disadvantages, such as high manufacturability and cost, as well as some dependence on weather conditions, in addition have limitations on use. The rate of development of open pit mining in Kazakhstan and worldwide is quite high, but there are a number of problems that need to be solved. One of the problems is the development of effective methods for controlling the stability of rocks in open pit mines. The analysis of works [1-4] has uncovered a predicament that defies a definitive resolution, necessitating the implementation of diverse methodologies. To address these prevailing challenges, the indispensable incorporation of a technology focusing on the advancement of sensors utilizing single-mode optical fibers becomes imperative. And the main objective of this research is to create sensors that possess a substantial degree of instability at their sides and edges. This objective has been corroborated by the findings of various simulation experiments conducted by the authors in [5, 6], who extensively discussed the advantages and disadvantages of fiber-optic sensors. Currently, there are many approaches available, each of which has been shown to be effective. However, the main challenge is to develop and implement an innovative technique using fiber-optic technology that combines all the benefits described in the research [7].

Scientists from various countries are actively working on the problem described above, and are exploring different approaches to solve it. Some of the proposed methods include the development of geotechnical radar, the application of geo-scanning methods, as well as the use of fluorometric approach and other innovative techniques. A comprehensive analysis of existing control methods and tools with a detailed description of their advantages and disadvantages is quite well researched and described in [8], which supports the concept proposed in this study. However, the problem of ensuring the stability and safety of open pit sides is still relevant and requires further improvements and search for new solutions, taking into account the variety and complexity of mining operations performed at the open pit or open pit mine, as well as mining and geological conditions [9]. Some innovative methods have limited application due to the high cost of capital and operating costs, which significantly exceed the cost of traditional instrumental measurements. Among the existing methods [8] for measuring and controlling the condition of quarry faces, the most favored are the following: geometric and hydraulic levelling, planning and spatial three-layer measurement, profile line distance measurement using light meters, profile line slope measurement, special ground light stone measurement and automated remote information transmission system for determining the relative displacement of the control point. However, the last method listed above, the automated remote information transfer system, is the most promising and acceptable to the modern mining industry, which tends to utilize digital technology. The scientific substantiation of geological support for controlling the stability of quarry sides allows the development and implementation of observation methods using modern geodetic equipment and technologies, such as high-precision observations using electronic total stations, instrumental observations using global navigation satellite systems, automated system «GEOMOS», ground-based laser scanning and radar interferometry to observe the movement of rocks and the earth's surface. However, the main drawbacks of existing methods are their dependence on obstacles, susceptibility to radio interference and the requirement for expensive equipment.

The control of pit wall stability relies mainly on an accurate assessment of the conditions and causes of deformation. Prediction and monitoring of pit wall stability are key tasks in open pit mining. When considering the factors affecting pit wall stability, the following should be kept in mind: the type of disturbance, the activity of the fracture process, its nature and configuration, as well as the type of deformation and its duration, the parameters of the tool array and the characteristics of the sides. Without systematic monitoring of these parameters, it is difficult to obtain such information.

One of the promising solutions is the use of fiber-optic technologies in the systems for controlling the stability of quarry sides. Creation of a digital control system based on a light wave instead of an electrical signal can partially solve this problem. It will allow not only to save a lot of money when creating a complex of control of the stability of the pit walls, but also to digitalize separate processes of mining production. Optical fiber has a number of advantages over traditional instrumental and electrical measurement systems such as total stations. It does not require the use of electric current for its operation, has a low signal attenuation coefficient, is insensitive to electromagnetic interference and is fire safe [9].

The paper [10] describes the research of the physical and mathematical model of the system of controlling the stability of quarry sides using optical fiber, its physical basis of construction. In addition, it describes the issues that are related to the development of a system for controlling the stability of quarry sides using optical fiber. A fiber-optic point sensor is used in a quarry wall stability monitoring system using optical fiber. This sensor is based on a laboratory specimen that uses a dual Mach-Zehnder interferometer, which ensures zero drift. It also uses a single-mode optical fiber to control the drift with a change in sensitivity and has low temperature resistance. In addition, similar works by foreign researchers who also work with optical fiber and build fiber-optic sensors were analysed.

The research paper [11] discusses a new water pressure sensor, confirming the effectiveness of using Bragg grating for pressure monitoring. In paper [12] published in 2011, researchers presented a system for continuous pressure monitoring at roof and slab, where the main loads on the measured masses gradually shift. The effectiveness of this system was demonstrated in the same work [12] through the evaluation of the sheathing characteristics to ensure its reliable performance in different geological conditions. [13] provides information on strain measurements in the underground mining field, wherein measuring strain over an infinite length aids in correcting the strain field generated by underground operations outside the fault zone. Field inspection has the advantage of being able to continuously monitor strains under a variety of actions, including tension, compression and shear, as well as respond to tensile strains due to the ability to detect localised shear or expansion in volumetric heterogeneities.

In their paper [14], the authors describe the development and testing of a novel quarry safety monitoring system using Bragg networks. This system offers a number of advantages over traditional monitoring devices, including accurate and reliable remote monitoring of quarry operations. The researchers, who are also authors of another paper [15], present test results demonstrating the high deformation characteristics of a high-strength stainless steel optical fibre. This optical fibeк can be connected to a concrete anchor with uniform deformation, indicating its potential for theoretical and experimental monitoring of quarry movement. In addition, another research paper [16] addresses the problem of work safety by investigating the stability conditions of large-sized mining tools. This work presents an innovative analysis method that combines digital photogrammetry with distributed fibeк-optic sensors, unmanned aerial vehicles and topographic and geotechnical control systems to verify and monitor stability conditions.

The literature review has shown that the existing methods do not fully provide a solution to the problem of board stability control in terms of their efficiency, ease of operation and energy consumption. It should also be noted that the cost of some technical means is quite high for mining companies, which leads to the use of manual labor, which hinders the practical implementation of digital technologies. The human factor also brings some problems with the accuracy and timeliness of detection of potential rock collapse centers. The proposed method takes into account all modern peculiarities of science and technology development as well as the necessity of transition from electronic to optical technologies. Fiber-optic sensors will provide automatic control of rock displacement with minimum cost of one measurement point and minimum energy consumption.

3. Experimental part

The circuit diagram of the pit wall stability sensor based on optical fiber can be explained on the basis of fundamental physical laws, such as the laws of optics and Hooke's law. The laws of optics and Hooke's law play a key role in the circuit diagram of the optical fiber-based pit wall stability sensor. The law of refraction of light (Snellius' law) describes the change in the direction of a light beam when moving from one medium to another. This law is taken into account when calculating the change in the optical path of light in an optical fiber when its length changes due to displacements. Law of conservation of energy in optics, according to this law, the energy of a light beam is conserved during its passage through optical systems. This is taken into account in determining light intensity and phase in the interference phenomena used to measure the displacement of an optical fiber. Hooke's law describes the relationship between stress and displacement in elastic materials. According to this law, stress (tension or compression stress) is proportional to displacement with a constant coefficient of proportionality called the modulus of elasticity or Young's modulus. In the context of a pit wall stability sensor, Hooke's law is used to interpret optical fiber displacement data, which is converted into stresses in rock masses. The measured displacements are used to determine the stresses in the rock masses, which allows the level of pit wall stability to be assessed. Consequently, the laws of optics and Hooke's law provide the fundamental principles for the operation of a pit wall stability sensor based on optical fibers, allowing to measure displacements and stresses in rock masses with high accuracy and reliability. The main steps of such a sensor are summarised in Table 1.

Table 1. Basic stages of sensor operation.

Change of optical fiber length under stress	Measurement of change using interference	Signal conversion	Data visualisation and analysis
- a fiber impregnated with a certain material is installed along the pit wall - under the action of stresses or deformations occurring in the rock masses - the length of the optical fiber changes, this change in length leads to a change in the optical characteristics of the fiber	- interferometry is used to measure changes in the length of an optical fiber - interference occurs between reflected light waves from different parts of the fiber - a change in the length of the fiber causes a change in the phase of the interfering waves, which can be measured by	- the measured phase change of the interfering waves is converted into a strain or stress value - signal processing algorithms are used for this purpose, which can be implemented in the software of the complex	- the obtained data on deformations and stresses in rock masses are displayed on the monitor for operators - this allows operators to monitor the stability of the pit walls in real time and take appropriate precautions

Thus, the operating principle of the sensor is based on the use of optical fiber to measure deformations in rock massifs, as well as on signal processing methods to analyse the obtained data. This allows operators to effectively monitor the stability of pit sides and prevent dangerous situations.

In this paper, fiber-optic sensors based on a two-way fiber-optic interferometer are considered, which are simple to fabricate and simple to process signals. All types of fiber-optic sensors have certain disadvantages, for example, in sensors based on interferometers, a change in sensitivity is observed, as well as in long measuring channels, the influence of temperature interference and a change in the refractive index is observed, which leads to a «signal freeze» due to a change in the initial value of the phase of light wave propagation through the core of optical fibers. The problems described above are more typical of single-mode optical fibres as they are used to observe objects at distances up to 30 km. Multimode fibres, although less susceptible to temperature interference, can operate effectively over shorter distances of 500-1000 metres. One of the solutions to completely eliminate the disadvantages of two-way fiber-optic interferometers is signal processing software using artificial intelligence algorithms. In this paper, it will be proposed to develop fiber-optic sensors based on the double Mach-Zehnder interferometer principle and using single-mode optical fiber for strain (shear) monitoring. They will have variable sensitivity and low sensitivity to temperature changes to minimise drift.

A Mach-Cender dual beam interferometer fiber sensor based on Single Mode optical fiber is proposed to control the bias change in sensitivity and the effect of zero drift caused by temperature interference. In order to change the sensitivity of the strain meter, the design was modified. The optical fiber is wound on two half-discs and can be made of plastic (Figure 1), where 1 is beam source with wavelength 1310-1625 nm, 2 is optical connector, 3 is optical fiber, 4 is movable half-disc, 5 is fixed half-disc, 6 is resilient element (damper), 7 is movable stand, 8 is fixed half-disc mounting point, 9 is sensor housing, 10 is optical wattmeter. The obtained results are explained by the inverse relationship between the values of the elasticity coefficient: the greater the number of turns of the optical fiber, the lower the elasticity coefficient. To really test the scheme, a laboratory sample of the optical fiber sensor based on the Mach-Cender interferometer was created (Figure 2). Displacement is performed by tightening the tension sleeves. When moving the ends of the ferrule in which the optical fibre is inserted, a distance of up to 3 mm can be formed between them; if necessary, the measuring range can be increased to 100 mm by extending the ferrule. However, there are limitations associated with the parameters of the ferrule surrounding the ends of the optical fiber and the tube through which the ferrule moves. To increase the distance between the ends of the fiber, multiple sensors may be connected in series or a transfer mechanism may be used. As the distance between the ends of the optical fiber increases, the characteristics of the light, such as its intensity and propagation phase, change, which is reflected in a change in the shape of the light spot. The greater the separation between the ends of the optical fiber, the greater the degree of additional loss and optical power loss. These changes are carefully recorded by the control hardware and software system and visualised on the screen.

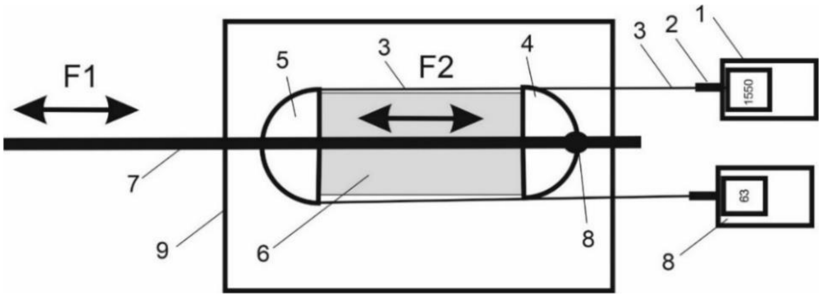

Fig.1. Strain measurement method using fiber optic sensors

Fig. 2. Laboratory sample of a fiber optic sensor based on a Mach-Zehnder interferometer

In the experiment, the initial conditions were: tension force on optical fiber in 0.5 mm increments for optical fiber with wavelength 650, 1310, 1550 nm in chamber conditions at air temperature from 22^{0}C to 23^{0}C with relative humidity within 60%. Corning SMF 9/125 µm quartz Single Mode fiber (ITU-T G.652.Standard D) is used as an optical fiber sensor. The optical fiber has a 245 micron thick primary coating. The interferometer arm contains spools with 2.03km and 2.01km optical fibers respectively, connected using a standard 20m jumper, with SC connectors on both sides. The power losses passing through the arms of the fiber-optic sensors were determined using experiments with different boundary values. Measurements of displacement values of the instrument array were repeatedly carried out, experimental data were processed by methods of mathematical statistics with the help of computer programmes. To ensure the accuracy of the obtained results, Student's criterion with a confidence interval of 0.95 will be used. The measures taken will make it possible to achieve high indicators of adequacy, neutrality, validity in relation to the processes and phenomena under study in order to identify various errors, according to the recommendations.

The obtained experimental data were processed using the computer programme Wolfram Alpha (computational knowledge engine), and a graph (Figure 3) of the dependence of the change in the additional light wave losses as a function of the applied tension force was plotted. Using the computer programme Wolfram Alpha, mathematical expressions of various approximations were obtained. Experimental processing of the results was carried out taking into account the minimum value of the Akaike information criterion, and a second-degree approximation with the coefficient of determination R^2=0.982 was chosen as the best option. The laboratory sample of the fiber-optic sensor based on the Mach-Zehnder interferometer demonstrated sufficiently high linearity and accuracy of measurements. After appropriate modification of its design, it can be successfully applied for control of array deformation. Automated approximations of data for optical fibers with wavelengths of 650, 1310, 1550 nm using Wolframalpha software were carried out, data and graphs of dependence of optical fiber loss values were obtained. For example, for a wavelength of 650 nm the dependence graph (Figure 3) of the value of optical fiber losses at step-by-step increase of tension and data diagnostics is presented.

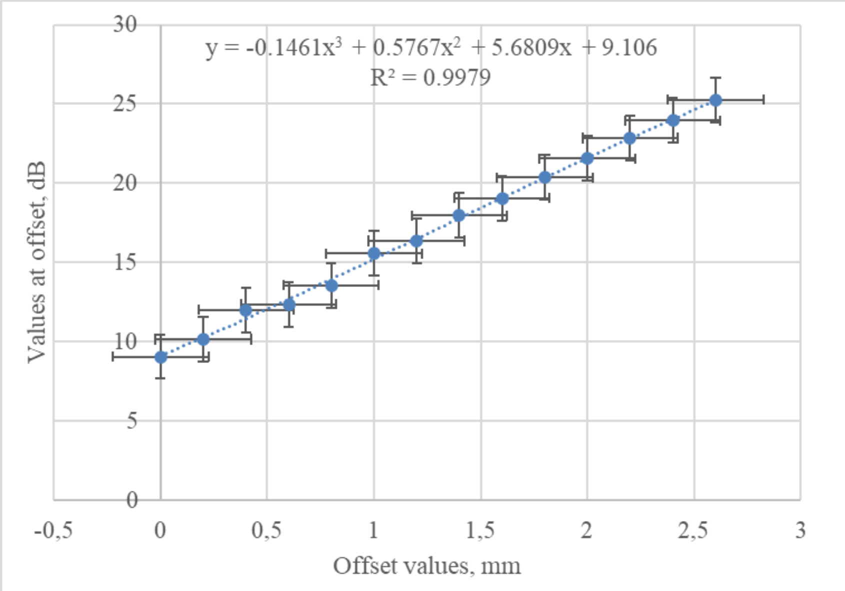

Fig. 3. Graph of the dependence of optical losses on the value of the reference point shift

The results of research in the field of creating a hardware and software complex for controlling the stability of quarry sides using optical fiber are presented as follows.

1. Creation of the prototype of the complex, where the research included the design and construction of the hardware part of the complex, including optical sensors, measuring devices and data transmission systems, as well as software for processing and analysing the obtained data.

2- Testing in laboratory conditions, where the prototype of the complex was subjected to testing in order to assess its efficiency and reliability in real conditions. During the experiments the parameters of measurement accuracy, stability of the system operation and the ability to react promptly to changes in the environment were evaluated.

3. Data acquisition and analysis, where the collected data on changes in the stability of the quarry sides were subjected to analysis using signal processing and statistical analytical methods. This allowed the identification of the main trends and characteristics of changes in rock masses and the assessment of the hazard level of certain areas.

4. Conclusions, where the performance of the complex, its advantages and limitations were determined on the basis of the research results, and recommendations for further improvement of the system were developed. These conclusions can be used to optimise the processes of controlling the stability of quarry sides and improve safety at work.

Such research results are important for the mining and construction industry, as they can contribute to the improvement of technologies for controlling and managing mining processes, as well as reducing the risks of accidents.

4. Results and discussion

As already mentioned, the fiber-optic system that ensures the safety of open-pit mining consists of three main parts: a radiation source, a fiber-optic sensor, a device for data processing and information output. The first two elements are described in detail and studied in the scientific literature. The most important element is the latter, since the effectiveness of measurements and the reliability of results depend on its operation. It is necessary to develop a data processing device and use high technologies associated with artificial intelligence algorithms necessary to output information that meets all modern requirements.

It is noted in the literature that little information about this device has been published, and the developed software package is not freely available. The more complex the devices for data processing and information output, as well as its algorithms related to decision-making, the more accurately it provides measurements and eliminates all errors associated with various interference. For example, in a distributed fiber-optic system, there may be a significant influence of temperature resistance, which leads to a drop or freezing of the signal. Complicating the algorithm of data processing and decision-making is one of the ways to create efficient devices for processing and extracting data in all respects, but this requires certain equipment and software, which significantly increases the cost of the monitoring system. In addition to the costs of creating a monitoring system, the buyer will need to spend money on expensive and long-term research work. Given the lack of widespread demand and limited use, this creates a fairly high cost of fiber-optic tracking systems based on fiber-optic technologies, which limits the scope of their application.

Also, a number of technical problems have not been fully solved, which do not allow for their widespread implementation at mining enterprises. Taking into account the above, work has begun on the creation of its own hardware and software complex for four measuring channels. So far, the physical number of channels is limited to four, depending on the limited computing capabilities of the computer and the performance of the graphics card, as well as the developed algorithms of the program, but in the future their number will increase to the real needs of the enterprise. An increase in the number of channels leads, first of all, to an increase in cost due to an increase in the length of fiber-optic control cables, but security issues are a priority. If there is a production need, the monitoring system can manage several thousand reference stations at the same time. The appearance of the window of the hardware and software complex is shown in Figure 4.

Intellectual software based on machine learning algorithms was specially developed for the operation of fiber-optic sensors. The hardware-software complex can be multi-channel and can simultaneously work with several fiber-optic sensors, which can be remote from the data processing unit at a distance of up to ten km. The basis of the hardware-software complex is the use of OpenCV (Open Source Computer Vision Library) elements. The OpenCV version for Python programming language is used in this complex. The generation and display of graphs are carried out with the help of Matplotlib library in Python programming language. Matplotlib allows visualizing data using two-dimensional (2D) graphics, and also supports three-dimensional (3D) graphics. The interface of the software and hardware complex is implemented using the Tkinter library. The main window of the programmed, shown in Figure 4, contains the following functional elements: 1 is background start control block and stop button; 2 is camera settings block; 3 is activity monitoring block; 4 is status and signal indicators block, including motion registration function with time logging capability; 5 is button to save settings with «Apply» inscription [7,8].

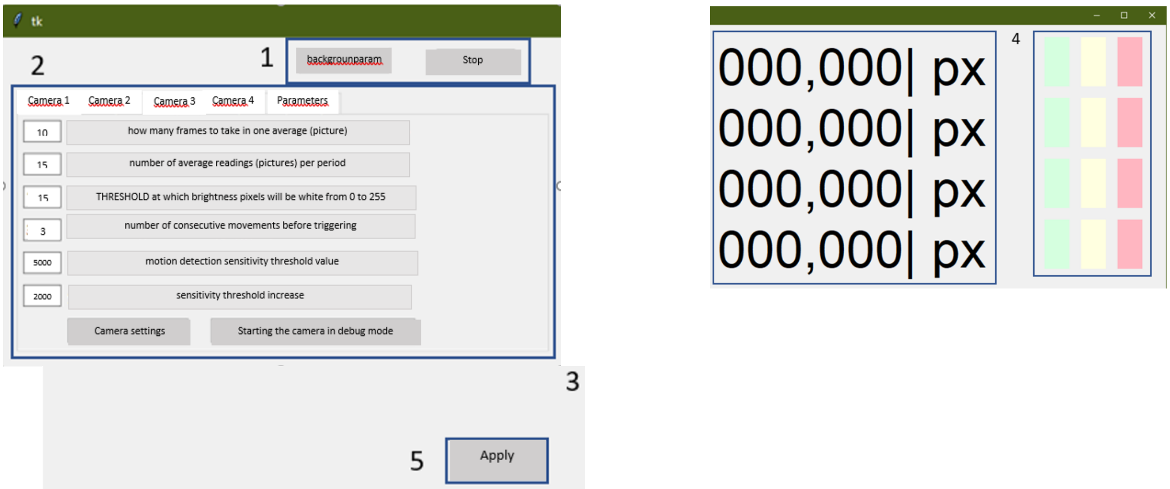

Fig. 4. The appearance of the hardware and software complex

The hardware-software complex has the ability to analyze various disturbances formed by external influences on the fiber-optic sensor. For this purpose, special algorithms have been developed that distinguish changes in the optical wave propagation parameters when the ambient temperature changes, as well as external vibration effects associated with the technological process [7]. The hardware-software complex is capable of evaluating the rate of change of the measured parameters and detecting false signals formed by various disturbances, as well as automatically perform calibration at startup. The rate of amplitude growth and frequency of influences at occurrence of interferences differs significantly from the parameters formed at real displacement of rocks that allows to perform machine learning for recognizing interferences and real signals. Also, to combat interference hardware-software complex has a number of settings that allow you to deal with external interference, which ensures the reliability of its work and suitability for practical use.

5. Conclusions

Based on the principles of physical kinetics, statistical theory and continuum electrodynamics, an inhouse method was developed. In this work, in accordance with the developed experimental measurement scheme, the sensitivity of the photodetector is determined by the dynamic range of measurements, which includes such parameters as the power of the radiation source (laser), the number of measurement channels, optical power losses of the light pulse propagating along the optical fiber core, losses caused by each connector (connectors, optical fiber welding points), the optical length of the channel, the level of reflected power, micro bends of the optical fiber, and the micro bends of the optical fiber. The aim of this approach is to compare the calculated results with experiment to determine the effect of small deformations of the optical fiber fabricated sample on the strain sensor readings.

In-house tests have shown that the control complex using a fiber-optic sensor has a sufficiently high accuracy and linearity of displacement measurement. The control complex equipped with a fiber-optic sensor has a number of advantages over the existing observation reference stations, which do not have the ability to automate the process of controlling the displacement of rock faces and timely warn the working personnel of the danger. An important point is that the proposed control complex with the use of fiber-optic sensors is fully explosion-proof, as it uses optical fiber through which the light wave propagates. In addition, it can be noted that the design of the sensor itself is simple enough to ensure low cost of its manufacture and does not create problems with operation in the cold climate of Kazakhstan. The created control complex using a fiber-optic sensor can work simultaneously with four such sensors, but in the future their number will be increased up to 32 for one measuring module, which is quite enough for monitoring the mining zone at open-pit mines.

The main objective of the project is to address production concerns linked to enhancing mining operations' safety. Utilizing fiber-optic monitoring systems enables real-time remote monitoring of quarry stability. Findings from laboratory experiments showcase that the developed fiber-optic sensor exhibits highly satisfactory linear characteristics and boasts low power consumption when compared to electrical measuring systems, even at distances ranging from to 30 km. The proposed technical solution is a new stage in the development of systems for monitoring the geotechnical condition of rocks in open pit mines.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement

Madi P.Sh.: Investigation, Data curation, Writing- Original draft preparation; Al'kina A.D.: Software, Visualization; Mekhtiyev A.D.: Conceptualization, Writing - Review & Editing, Project administration; Yurchenko A.V.- Methodology, Validation, Resources. The final manuscript was read and approved by all authors.

Acknowledgments

This research has is funded by the Ministry of Trade and Integration of the Republic of Kazakhstan (Grant No. BR19980899 «Development of a system for monitoring the geotechnical state of mine workings and quarries based on intelligent fiber-optic sensors»).

References

1 Ozhigin S.G., Ozhigina S.B., Ozhigin D. Method of Computing Open Pit Slopes Stability of Complicated-Structure Deposits. *Journal of the Polish Mineral Engineering Society* (*Inzynieria Mineralna)*, 2018, 41(1), pp. 203 - 207. https://doi.org/10.29227/IM-2018-01-32

2 Dorokhov D.V., Nizametdinov F.K., Ozhigin S.G. et al. A Technique for Surveying of Ground Surface Deformations in Mine Fiel. *Journal of Mining Science*. 2018, Vol.54 (5), pp. 874–882. https://doi.org/10.1134/S1062739118055011

3 Sannikova A.P., Bazykina L.R., Ozhigin S. Methodology for effective determination of rock jointing in calculation of open pit edges. *Journal of Industrial Pollution Control*, 2017, Vol.33. pp. 852 – 855. https://www.researchgate.net/publication/318272335_Methodology_for_effective_determination_of_rock_jointing_in_calculation_of_open_pit_edges/references

4 Ozhygin D., Šafář V., Dorokhov D., Ozhygina S., Ozhygin S., Staňková H. Terrestrial photogrammetry at the quarry and validating the accuracy of slope models for monitoring their stability. *Proceeding of the IOP Conference Series: Earth and Environmental Science*, 2021, Vol. 906(1), pp. 012062. https://doi.org/10.1088/1755-1315/906/1/012062

5 Yugay V.V., Madi P.Sh., Ozhigina S.B., Gorokhov D.A., Alkina A.D. Questions of application of fiber-optic sensors for monitoring crack growth during rock deformations. *Actual Problems of Radiophysics International Conference (APR 2021) Conference Series. Journal of Physics,* 2021, 2140 pp. 012037. https://doi.org/10.1088/1742-6596/2140/1/0120373

6 Mekhtiyev A.D., Yurchenko A.V., Kalytka V.A., Neshina Y.G., Alkina A.D., Madi, P.Sh. A Fiber-Optic Long-Base Deformometer for a System for Monitoring Rocks on the Sides of Quarries. *Tech. Phys. Lett*., 2022, Vol. 48, Is. 4, pp. 207 – 209. https://doi.org/10.1134/S1063785022070057

7 Yugay V., Mekhtiyev A., Madi P., Neshina Y., Alkina A., Gazizov F., Afanaseva O., Ilyashenko S. Fiber-Optic System for Monitoring Pressure Changes on Mine Support Elements. *Sensors*, 2022, Vol. 22(5), pp.1735. https://doi.org/10.3390/s22051735

8 Madi P.Sh., Alkina A.D., Yurchenko A.V., Mekhtiyev A.D., Aimagambetova R.Zh. Automated system hardware and software control complex. *Kazan State Power Engineering University Bulletin*, 2022, Vol. 14. No. 3(55), pp. 126-143. https://cyberleninka.ru/article/n/apparatno-programmnyy-kompleks-dlya-kontrolya-smescheniya-bortov-karierov/viewer

9 Ozhigin S., Ozhigina S., Ozhigin D. Method of Computing Open Pit Slopes Stability of Complicated-Structure *Deposits Journal of the Polish Mineral Engineering* Society. Inzynieria Mineralna, 2018, Vol. 41(1), pp. 203-207. https://doi.org/10.29227/IM-2018-01-32

10 Mehtiyev A.D., Yurchenko A.V., Neshina E.G., Alkina A.D., Madi P. Physical bases of pressure sensors creation on the basis of light refractive index change at optical fibre microbending. *News of higher educational institutions: Physics*, 2020, Vol.63, No.2, pp. 129 – 136. https://doi.org/10.17223/00213411/63/2/129 [in Russian]

11 Liu, X.-H & Wang, C. & Liu, Tongyu & Wei, Y.-B & Lu, J.-S. Fiber grating water pressure sensor and system for mine. *Acta Photonica Sinica*, 2009, Vol. 38, No.1, pp.112-114. https://m.researching.cn/articles/OJc862bfb9be78ec56

12 Kumar Atul, Kumar Dheeraj, Singh U., Gupta P S., Shankar Gauri. Optimizing fibre optics for coal mine automation *International Journal of Control and Automation*, 2011, Vol. 4, No.3, pp. 63 – 70. https://article.nadiapub.com /IJCA/vol4_no3/2.pdf

13 Madjdabadi B., Valley B., Dusseault M.B., Kaiser P.K. Numerical study of grout–rock mass interaction effect on distributed optical fibre sensor measurements. *Proceedings of the 7th Intern. Conf. on Deep and High Stress Mining, Australian Centre for Geomechanics, Perth.*, 2014, pp. 457-468. https://doi.org/10.36487/ACG

14 Yiming Zhao, Nong Zhang and Guangyao Si. A Fiber Bragg Grating-Based Monitoring System for Roof Safety Control in Underground Coal Mining. *Journal List Sensors (Basel)*, 2016, Vol.16(10), pp. 1759. https://doi.org/10.3390/s16101759

15 Hu T., Hou G., Li Z. The Field Monitoring Experiment of the Roof Strata Movement in Coal Mining Based on DFOS *Sensors*, 2020, Vol. 20(5), pp. 1318. https://doi.org/10.3390/s20051318

16 Lanciano Ch., Salvini R. Monitoring of deformation and temperature in a career with the help of distributed fiber-optic Brillouin sensors. *Sensors*, 2020, Vol. *20*(7), pp.1924. https://doi.org/10.3390/s20071924

AUTHORS' INFORMATION

Madi P.Sh. – Candidate of Techn. Sciences, Department of Electrical Equipment Operation, S. Seifullin Kazakh Agrotechnical University, Astana, Kazakhstan; ORCID iD: 0000-0001-5930-8112; peri@mail.ru

Al'kina A.D. – Master, Department of Energy Systems, Karaganda Technical University named after Abylkas Saginov, Karaganda, Kazakhstan; ORCID iD: 0000-0003-4879-0593; alika_1308@mail.ru

Mekhtiyev, A.D. – Candidate of Techn. Sciences, Professor, Department of Electrical Equipment Operation, S. Seifullin Kazakh Agrotechnical University, Astana, Kazakhstan; ORCID iD: 0000-0002-2633-3976; barton.kz@mail.ru

Yurchenko A.V. – Doctor of Techn. sciences, Professor, Research School of Physics of High-Energy Processes, National Research Tomsk Technical University, Tomsk, Russian Federation; Department of Innovative Technologies, Tomsk State University, Tomsk, Russia; ORCID iD: 0000-0002-7854-549; niipp@inbox.ru