ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ
Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
НАУК РЕСПУБЛИКИ
КАЗАХСТАН
Satbayev University

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
Satbayev University

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

1 (457)

JANUARY – FEBRUARY 2023

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 1, Number 457 (2023), 166-176
https://doi.org/10.32014/2023.2518-170X.267

UDC 622:681.7

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MONITORING THE GEOTECHNICAL CONDITION OF UNDERGROUND MININGS USING DIGITAL TECHNOLOGIES

Abstract. This article discusses one of the methods of monitoring the state of the geotechnical state of mining in real time. One of the problems of operating reference stations is the constant inspection by the marker services for the technical condition of the mine workings. The authors describe the developed fiber-optic monitoring sensor capable of monitoring and warning about abnormal situations of the geotechnical state of underground mining. A detailed analysis of the use of such devices and scientific achievements in mining enterprises is presented. Fiber-optic sensor design. A fiber-optic sensor for the displacement of rocks of the mine workings and a measurement system were developed. The work uses a unique method for controlling changes in the properties of a light wave passing through an optical fiber, which significantly reduces the cost of measuring a single point. The research included monitoring the condition of the mining workings of the Tentekskaya mine. According to the results of the research, a graph of the dependence of optical losses on the displacement value was obtained, an automated approximation of the data was carried out, all changes are recorded by the hardware and software control complex and displayed on the screen. The developed fiber-optic displacement sensor together with the hardware and software control complex have proven their operability and safety of operation in mining enterprises.

Key words: Fiber optic sensor, monitoring system, rock displacement, safety, optical fiber, deformation, safety.

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ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАРДЫ ПАЙДАЛАНАТЫН ЖЕР АСТЫ КЕН ҚАЗБАЛАРЫНЫҢ ГЕОТЕХНИКАЛЫҚ ЖАҒДАЙЫН БАҚЫЛАУ

Аннотация. Бұл мақалада нақты уақыт режимінде тау-кен қазбаларының геотехникалық жағдайын бақылау әдістерінің бірі қарастырылады. Тірек станцияларын пайдалану проблемаларының бірі-тау-кен қазбаларының техникалық жай-күйін маркшейдерлік қызметтердің үнемі тексеріп отыруы. Авторлар жерасты тау-кен қазбаларының геотехникалық жағдайының штаттық емес жағдайларын бақылауға және ескертуге қабілетті әзірленген талшықты-оптикалық бақылау датчигінің сипаттамасын береді. Тау-кен кәсіпорындары жағдайында осындай құрылғылар мен ғылыми жетістіктерді қолданудың егжей-тегжейлі талдауы ұсынылған. Талшықты-оптикалық сенсордың дизайны. Тау-кен жыныстарының ығысуының талшықты-оптикалық сенсоры және өлшеу жүйесі жасалды. Жұмыста оптикалық талшық арқылы өтетін жарық толқынының қасиеттерінің өзгеруін бақылаудың бірегей әдісі қолданылады, бұл бір нүктені өлшеу құнын айтарлықтай төмендетуге мүмкіндік береді. Зерттеулер «Тентек» шахтасының тау-кен қазбаларының жай-күйін бақылауды қамтыды. Зерттеу нәтижелері бойынша оптикалық шығындардың орын ауыстыру мәніне тәуелділігі графигі алынды, деректерді автоматтандырылған жақындату жүргізілді, барлық өзгерістер аппараттық-бағдарламалық бақылау кешенімен тіркеліп, экранда көрсетіледі. Әзірленген талшықты-оптикалық орын ауыстыру датчигі аппараттық-бағдарламалық бақылау кешенімен бірлесіп, тау-кен кәсіпорындары жағдайында жұмыс қабілеттілігі мен пайдалану қауіпсіздігін дәлелдеді.

Түйінді сөздер: талшықты-оптикалық сенсор, бақылау жүйесі, тау жыныстарының жылжуы, қауіпсіздік, оптикалық талшық, деформация, қауіпсіздік.

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МОНИТОРИНГ ГЕОТЕХНИЧЕСКОГО СОСТОЯНИЯ ПОДЗЕМНЫХ ГОРНЫХ ВЫРАБОТОК С ИСПОЛЬЗОВАНИЕМ ЦИФРОВЫХ ТЕХНОЛОГИЙ

Аннотация. В данной статье рассматривается один из методов мониторинга геотехнического состояния горных выработок в режиме реального времени. Одна из проблем эксплуатации реперных станций – это постоянный смотр службами маркшедеров за техническим состоянием горных выработок. Авторами приводится описание разработанного волоконно-оптического датчика контроля, способного контролировать и предупреждать о нештатных ситуациях геотехнического состояния подземных горных выработок. Представлен подробный анализ применения подобных устройств и научных достижений в условиях горных предприятий. Конструкция волоконно-оптического датчика. Был разработан волоконно-оптический датчик смещения пород горной выработки и система измерений. В работе используется уникальный метод контроля изменения свойств световой волны, проходящей по оптическому волокну, что позволяет значительно снизить стоимость измерения одной точки. Исследования включали в себя контроль за состоянием горных выработок шахты «Тентекская». По результатам исследований получен график зависимости оптических потерь от значения смещений, проведена автоматизированная аппроксимация данных, все изменения фиксируются аппаратно-программным комплексом контроля и отображаются на экране. Разработанный волоконно-оптический датчик смещения совместно с аппаратно-программным комплексом контроля доказали свою работоспособность и безопасность эксплуатации в условиях горных предприятий.

Ключевые слова: волоконно-оптический датчик, система мониторинга, смещение породы, безопасность, оптическое волокно, деформация, безопасность.

Introduction. The fiber optic displacement sensor can be used to control the displacement of rocks in coal mines that are dangerous for the sudden outburst of coal dust and methane gas. In these types of workings, an explosive atmosphere is formed that can ignite from any spark formed in electrical circuits during switching or their damage. The consequences of the explosion of coal dust and methane gas are a real disaster, and it leads to the most tragic consequences associated with the mass loss of life. The mines of the Karaganda coal basin are classified as super-category mines, which makes them extremely dangerous in terms of the likelihood of an explosion. On this basis stringent requirements are imposed on all the equipment in terms of intrinsic safety and explosion safety. Accordingly, all the electrical circuits must be protected against the impact of the mine atmosphere. This requires an explosion-proof design of any equipment, primarily the presence of a sealed metal shell that makes it quite massive and expensive.

One of the problems in the development of coal deposits by the underground method is destruction of the mine working support due to changing the pressure of rocks during the movement of the face whem mining coal. When the longwall face moves, the rock pressure is redistributed near the stope, and the load on the working support near the longwall face increases greatly. This leads to deformation of the elements of the support and its destruction, which causes a number of problems associated with the movement of people and equipment, and can also cause the danger of a sudden collapse of the working arch. The collapse of the workings can cause a serious danger to the miners and even their death. So, the development of methods and means of controlling the displacement of rocks caused by changes in the rock pressure is relevant. Figure 1 shows the case of deformation of a metal arched support with changing the rock pressure. It is seen that this situation becomes a significant problem for the movement of process equipment and causes a danger to workers, forms a threat of blockage in the mine. Elimination of the consequences requires a significant amount of material and human resources.

Figure 1 – Deformation of the metal arch support with changing the rock pressure

Relevance and problem definition

A timely reaction to the displacement of rocks with changing the rock pressure will make it possible to detect arch support in emergency zones in advance and to prevent its destruction. Displacement control will not only reduce the cost of support but also will permit to avoid tragic consequences in the event of a sudden collapse of the mine working roof.

Given the above, it can be noted that the use of electrical sensors is severely limited by safety regulations, since electric current can provoke a spark that causes an explosion. There is a rather complicated system of certification of electrical measuring systems operating in the conditions of mines dangerous for the explosion of coal dust and methane gas, as long enough tests are required, as well as approvals from various regulatory authorities. On this basis, at the present time, mechanical benchmark stations are used in mines to control the displacement of the mine working rocks caused by changes in the rock pressure. Their design is quite simple, it ensures their relatively low cost and relatively high reliability. One of the problems in the operation of benchmark stations is the need for periodic inspection by specialists of the marketing service followed by recording the results of control in a log. The outdated control system of the last century requires serious modernization and digitalization of the process of measuring the displacement of the mine working rocks. Therefore, the main task is to find new control methods that allow carrying out all the measurements remotely, while the explosion safety conditions must be ensured. One of the solutions can be a fiber optic displacement sensor of mine workings, since during its operation no electric current is used, and a light wave is transmitted through its core. Then, even if it is damaged, the possibility of an explosion of methane gas and coal dust is completely excluded.

Analysis of literature and scientific achievements in the field of using optical fiber as sensors

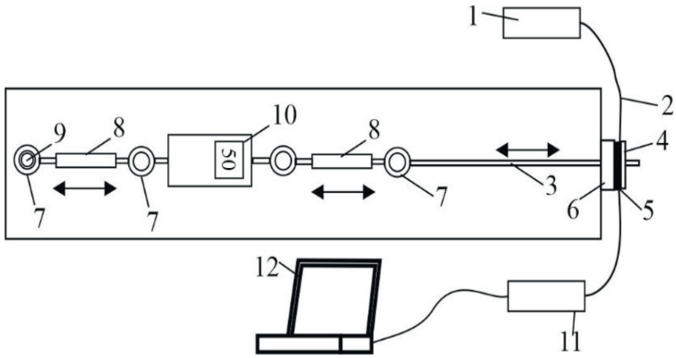
In sources (Yurchenko et al., 2013 Mekhtiev et al., 2020), all the advantages of using optical fiber as sensors are considered in detail. When analyzing various articles published in cited international scientific journals (Chotchaev 2016; Buimistryuk, 2013), there can be made a preliminary conclusion that the use of OF as rock displacement sensors is very promising. Such studies are dealt with by scientists in several countries of the world (Liu et al., 2013). A significant number of scientific studies that are close to the topic of this article is given in source (Yiming et al., 2016). Significant achievements in the field of improving the safety of mining operations using fiber optic sensors (FOS) belong to scientists from China and other countries of Southeast Asia (Kim et al., 2015; Buymistryuk, 2005; Wu et al., 2009; Qian et al., 2005; Wang et al., 2016). Analyzing work (Wang et al., 2016), it can be noted that the authors solve similar problems, since a sufficient number of coal mines are concentrated in China (Baibatsha et al., 2020). It can also be noted that there are publications that describe methods of controlling the rock pressure, as well as providing the information of the FOS design and presenting research results. The relevance of using FOS instead of mechanical and electrical systems for controlling rock displacement when the rock pressure changes, is beyond doubt (Kersey et al., 1997). There are publications with positive results of studying FOS and their practical approbation in the mines of China (Hong et al., 2016). The work at developing new types of FOS is being performed in Europe, Japan and Russia (Guo et al., 2019; Buymistryuk, 2011; Buimistryuk, 2013; Volchikhin, 2001). There is a positive experience of using FOS in various fields of industry including the aerospace industry, and quite effective fiber optic security systems have been developed on their basis (Kamenev et al., 2014). All the FOSs have a common essence of functioning, since a light source, an optical fiber, a photo-detector and a data processing device are used in all of them. Concluding the analysis, it can be said that the use of FIS to control the displacement of rocks in the working roof is very relevant, but there are a number of problems that need to be solved for their widespread use. All the FOSs use fairly well-known methods in their operation, and they can be grouped according to a certain principle of operation. On the basis of FOS, it is possible to build measuring systems of various types, for example, point, quasi-distributed, distributed ones. FOSs are based on the use of optical interferometers and reflectometers, fiber Bragg gratings, and long-period fiber gratings.

Developing a fiber optic rock displacement sensor and a measurement system

The above methods, for example, the use of FOS based on Bragg gratings, require the use of expensive equipment and have certain technological difficulties when used in coal mines that are dangerous for gas explosions. The cost of one measuring point also remains quite high. Therefore it was decided to use a different method for controlling changes in the properties of a light wave passing through the optical fiber. At the exit from the optical fiber, the light falls on the surface of the television matrix, while the spot contains a significant amount of noise, which sometimes makes it impossible to recognize changing the shape when the pressure on the optical fiber changes. It is known that at the exit from the OF a light spot is formed, the shape of which obeys the normal Gaussian distribution. It is natural that the single-mode fiber conducting through the core forms a lot of noise. The level of noise and phase shift of the propagation of a light wave depends on many factors, in particular on the temperature. When the temperature of the OF changes even by 1°C.

The refractive index can change and the operation of the measuring system as a whole can be disrupted. So, the temperature correction should be mandatory, and it is also necessary to evaluate the dynamics of changes in the pixel pattern against the background of constant noise. The use of a different method from the already known ones will simplify the design of the measuring system and sensors, as well as reduce the cost of one measuring point, which is extremely important for implementation.

Figure 2 shows the scheme of the experiment, where the main elements of the FOS are shown with the help of symbols. Light source 1 is a semiconductor laser with the wavelength of 650 nm and the power of 10 mW. A single-mode optical fiber of the G652 type is used as sensitive element. The frame for fixing the sensor is placed on a flat surface of the table, the load on the optical fiber is provided by two rotating tension couplings 8, between which load meter 10 is fixed that moves in the direction shown by the arrow. Between the 4^{th} and 6^{th} discs there is elastic damper 5. It is necessary to return the FOS to the initial position of measurements, and to prevents damage to the OF. Tension pin 3 has the M6 thread for fastening the discs and the damper into a single unit. Connecting ring 7 of one of tension couplings 8 is fixed on fixed support 9, which provides tension. The light wave from source 1 passed through OF 2 and hit the surface of the television matrix installed in pre-processing unit 11 that is connected to computer 12. The program windows for processing measurement data are displayed on the computer screen. The experiments have been carried out indoors at the temperature of 22°C.



1 - light source, 2 - sensing element, 3 - tension pin, 4 - movable disk, 5 - damper, 6 - fixed disk, 7 - connecting ring, 8 - tension coupling, 9 - fixed support, 10 - load meter, 11 - television matrix, 12 - computer

Figure 2 – Diagram of the experiment

Figure 3 shows the photos of the equipment used, as well as the design of the tensioner. The computer screen displays the windows of the program, which can give a numerical value of the load on the OF. The displacement is simulated by tightening the tension couplings. The optical fiber undergoes microbending, which changes the refractive index between the shell and the core, as a result of which the properties of the light wave at the exit from the optical fiber change. Changes in the properties of light relate to the intensity and phase of propagation, which is reflected in changing the shape of the light spot. In the process of fiber microbending, the well-known photo-elasticity effect arises; accordingly, the higher the pressure on the fiber, the greater the additional losses of propagating radiation. It is known that this is accompanied by the output of the light mode outside the shell and the loss of a part of the optical power. All the changes are recorded by the hardware-software complex and displayed on the screen.

The program has several windows for its configuration and operation. During the operation, the screen displays not only the numerical values of the load, by which the displacement is calculated but also the signal indicators, green, yellow and red, which are necessary to warn of a danger or vice versa of the normal operation of the system. With a sharp fluctuation in pressure and increasing the displacement parameter, a warning signal is given and a yellow indicator turns on indicating that the roof rocks have begun to move due to increasing the rock pressure.

Figure 3 - Equipment used

If the rate of pressure growth during a certain period of time exceeds the allowable value, then the alarm is activated and the red indicator lights up, which indicates the danger of a sharp collapse of the mine working. The program is initially set up for various measurement and triggering parameters depending on changing the pixel pattern of the light spot at the exit from the optical fiber (Figure 4). The data processing and noise reduction are also important. The source of noise is the laser, the fiber itself, and the ambient temperature. Without taking into account these circumstances, the operation of the measuring system is impossible due to the significant noise level. The number of channels of the measuring system is practically unlimited at the theoretical level but in practice it depends on the capabilities of the equipment used and the number of strands of the fiber optic communication cable. At the moment the system is able to work with 4 FOSs simultaneously. All the obtained data are stored in the computer memory and can be retrieved, if needed.

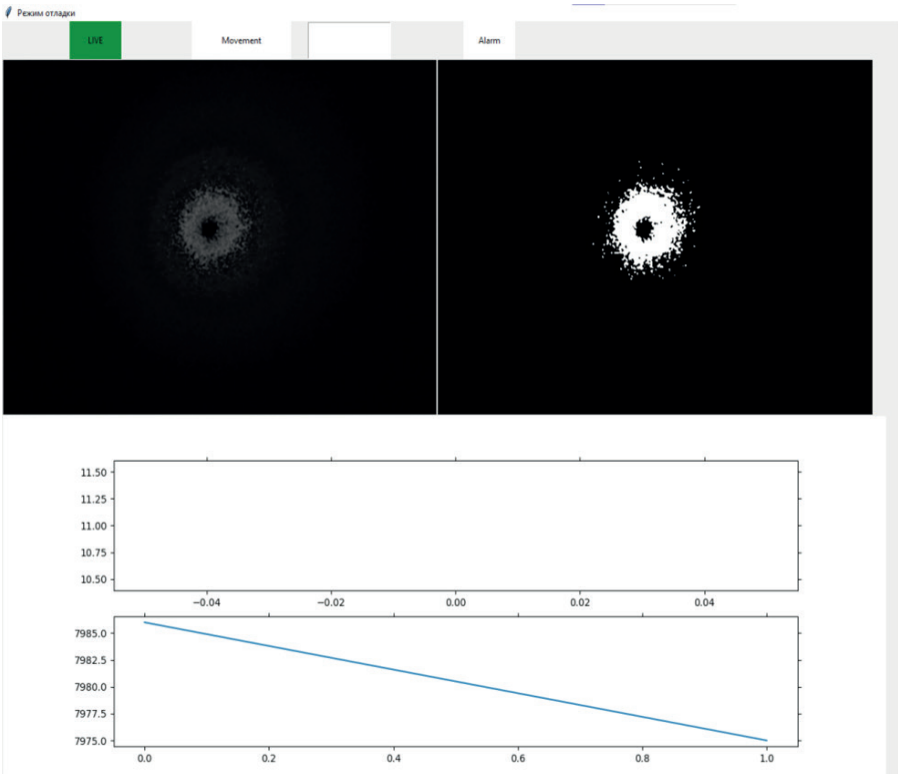


Figure 4 – Changing the pixel pattern of the light spot

Figure 5 shows the program setting window. There is also shown a light spot falling on the surface of a television matrix installed at the output of the optical fiber. The photo clearly shows that the core forms a lighter, and the shell a darker area. At the interfaces between the core and the shell, microfluctuations are visible that blur the outlines of the light spot. The same can be seen on the outer disk of the light spot.

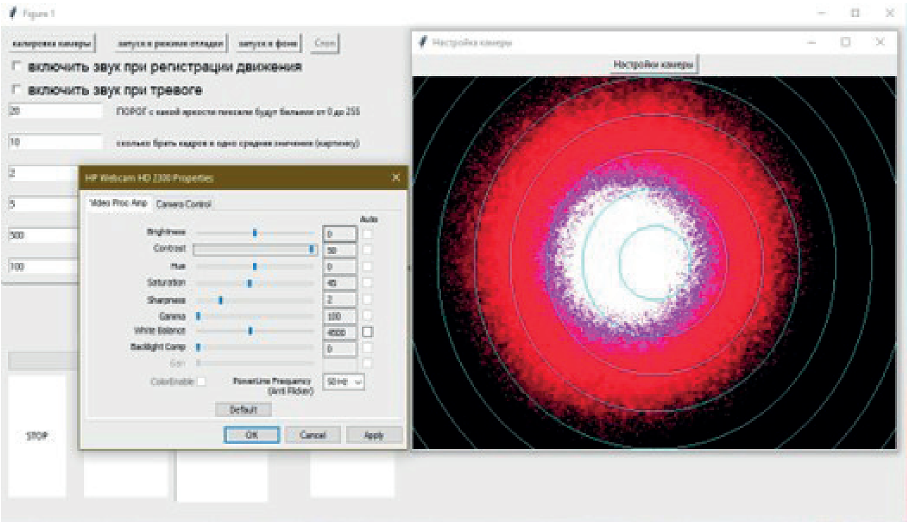


Figure 5 – Program setting window

As mentioned earlier, individual bursts that are interference, are determined by the hardware-software complex to exclude false alarms. To control the shape of the light spot, the capabilities of machine learning are used. They allow adapting the system to any conditions of the mining enterprise. The system is able to control changing the rock pressure and the displacement of the roof rocks by changing the level of additional losses, changing the intensity of the light wave incident on the surface of the photo-detector. The intelligent processing of the spot image allows tracking changes in the intensity of individual pixels. The hardware-software complex is capable of tracking the rate of changing the derivative of the light wave intensity over time.

The system can also step by step change its sensitivity. Initially it is set to the maximum sensitivity to control the initial displacements and to give warning signals to the operator, after which the parameters are automatically coarsened to accurately fix the displacement and to eliminate false measurements.

Conclusions. The system can step by step change its sensitivity. Initially it is set to the maximum sensitivity to control the initial displacements and to give warning signals to the operator, after which the parameters are automatically coarsened to accurately fix the displacement and to eliminate false measurements. The FOS has a fairly linear characteristic and is highly sensitive to any change in the displacement parameters when the pressure on the sensor changes. False alarms can be eliminated using software with a mandatory temperature correction.

The proposed fiber optic displacement sensor and quasi-distributed rock pressure monitoring system can be used in coal mines that are dangerous for the explosion of coal dust and methane gas. The hardware-software complex proved its efficiency. The proposed FOS is completely explosion-proof, since no electric current is used during its operation.

This research has is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14869145 «Development of an intelligent fiber-optic system for monitoring the geotechnical condition of mining pits and sections»).

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http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Заместитель директор отдела издания научных журналов НАН РК *Р. Жәлиқызы*
Редакторы: *М.С. Ахметова, Д.С. Аленов*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 18.02.2023.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
20,0 п.л. Тираж 300. Заказ 1.

Национальная академия наук РК
050010, Алматы, ул. Шевченко, 28, т. 272-13-19