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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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FIBER-OPTIC SYSTEM FOR CONTROLLING OPEN PIT SIDE ROCK DISPLACEMENT

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Abstract. The article deals with the development of a fiber-optic system for monitoring the displacement of open pit side rocks based on the use of optical-digital intelligent analysis of the optical parameters of fiber-optic sensors. The results are presented in a series of experiments aimed at establishing the pattern of changes in optical parameters under mechanical action on an optical fiber. In the experiments, the optical fiber has been stretched. It has been established that as the mechanical load on the optical fiber increases, there increase additional losses that can be converted into a unit of displacement. Experiments have shown that at different displacement values there is an increase in the number of white pixels that are formed due to mechanical action. The results obtained are explained by the inverse relationship between the amount of displacement and the number of white pixels. The control system performs an intelligent optical-digital analysis and transforms displacements into a pixel pattern. The greater the displacement, the more white pixels there are on the computer screen. Thanks to this technology, it is possible to determine with high accuracy the force of mechanical external impact on an optical fiber, which causes it to stretch, while the magnitude of the impact is directly proportional to the displacement. This principle is used to monitor soil deformations, to detect landslides, to monitor the condition of mines and the other objects where it is important to monitor soil movement. There are proposed a layout of fiber- optic sensors above a growing crack and a data processing unit for monitoring the displacement of rocks on the open pit sides.

Keywords: open pit, displacement, rock, fiber-optic sensor, geotechnical condition

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КАРЬЕР БОРТЫНДАҒЫ ТАУ ЖЫНЫСТАРЫНЫҢ ЖЫЛЖУЫН БАҚЫЛАУДЫҢ ТАЛШЫҚТЫ-ОПТИКАЛЫҚ ЖҮЙЕСІ

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Аннотация. Бұл мақалада оптикалық-талшықты датчиктердің оптикалық параметрлерін оптикалық-цифрлық интеллектуалды талдауға негізделген карьер бортындағы тау жыныстарының жылжуын бақылаудың оптикалық-талшықиы жүйесін әзірлеу мәселесі қарастырылады. Нәтижелер оптикалық талшыққа механикалық әсер ету кезінде оптикалық параметрлердің өзгеру заңдылығын анықтауға бағытталған бірқатар тәжірибелермен ұсынылған. Тәжірибелерде оптикалық талшық созылды. Оптикалық талшыққа механикалық жүктеме шамасы өскен кезде қосымша шығындар көбейетіні анықталды, оларды ығысу бірлігіне айналдыруға болады. Тәжірибелер нәтижесінде, әртүрлі орын ауыстыру мәндерінде механикалық әсерге байланысты пайда болатын ақ пикселдер санының артуы байқалады. Алынған нәтижелер орын ауыстыру мөлшері мен ақ пикселдер саны арасындағы кері байланысқа байланысты. Басқару жүйесі интеллектуалды оптикалық-цифрлық талдауды орындайды және орын ауыстыруларды пиксель үлгісіне айналдырады. Ығысу шамасы неғұрлым көп болса, компьютер экранында ақ пикселдер саны сәйкесінше көп болады. Осы технологияның арқасында оптикалық талшыққа механикалық сыртқы әсердің беріктігін жоғары дәлдікпен анықтауға болады, бұл оның созылуын тудырады, ал әсер ету мөлшері ығысу шамасына тура пропорционалды болады. Бұл принцип топырақтың деформациясын бақылау, көшкіндерді анықтау, шахталардың және топырақтың қозғалысын бақылау маңызды басқа объектілердің жағдайын бақылау үшін қолданылады. Карьер бортындағы тау жыныстарының жылжуын бақылау үшін өсіп келе жатқан жарықшақтың үстіне оптикалық-талшықты датчиктерді және деректерді өңдеу блогын орналастыру схемасы ұсынылады.

Түйін сөздер: карьер, орын ауыстыру, тау жынысы, оптикалық-талшықты датчик, геотехникалық жағдай

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ВОЛОКОННО-ОПТИЧЕСКАЯ СИСТЕМА КОНТРОЛЯ СМЕЩЕНИЯ ГОРНЫХ ПОРОД БОРТОВ КАРЬЕРА

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Аннотация. В данной статье рассматривается вопрос разработки волоконно-оптической системы контроля смещения горных пород бортов карьера, основанной на использовании оптико-цифрового интеллектуального анализа оптических параметров волоконно-оптических датчиков. Результаты представлены серией экспериментов, направленных на установление закономерности изменения оптических параметров при механическом воздействии на оптическое волокно. В экспериментах оптическое волокно подвергалось растяжению. Установлено, что при росте механической нагрузки на оптическое волокно увеличиваются дополнительные потери, которые можно конвертировать в единицу смещения. Эксперименты показали, что при различных значениях смещения наблюдается увеличение количества белых пикселей, которые формируются вследствие механического воздействия. Полученные результаты объясняются обратной зависимостью между величиной смещения и количеством белых пикселей. Система контроля выполняет интеллектуальный оптико-цифровой анализ и трансформирует смещения в картину пикселей. Чем больше смещения, тем больше белых пикселей на экране компьютера. Благодаря этой технологии можно с высокой точностью определить силу механического внешнего воздействия на оптическое волокно, которая вызывает его растяжение, при этом величина воздействия прямо пропорциональна смещению. Такой принцип применяется для отслеживания деформаций грунта, обнаружения оползней, контроля за состоянием шахт и других объектов, где важно отслеживать движение грунта. Предлагается схема размещения волоконно-оптических датчиков над растущей трещиной и блока обработки данных для контроля смещения горных пород бортов карьера.

Ключевые слова: карьер, смещение, горная порода, волоконно-оптический датчик, геотехническое состояние

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Конфликт интересов: *авторы заявляют об отсутствии конфликта интересов.*

Introduction

At present, the development of open pit mining of mineral deposits is characterized by modernization, the use of new technologies and technical solutions, which allows you to optimize the mining process, make it safer and more profitable. The key role is played by the technologies used to control the stability of the quarry side, since the technical and economic indicators of production and labor safety depend on this (Baibatsha et al., 2020). Due to the enormous size of quarries, it is necessary to constantly monitor their stability, especially during the mining process (Kamenev et al., 2014 ; Kim et al., 2015). To ensure safety at mining enterprises, it is necessary to introduce a system of automatic monitoring of the stability of quarry sides. Figure 1 shows that open pit side collapse can pose a danger to people and equipment.

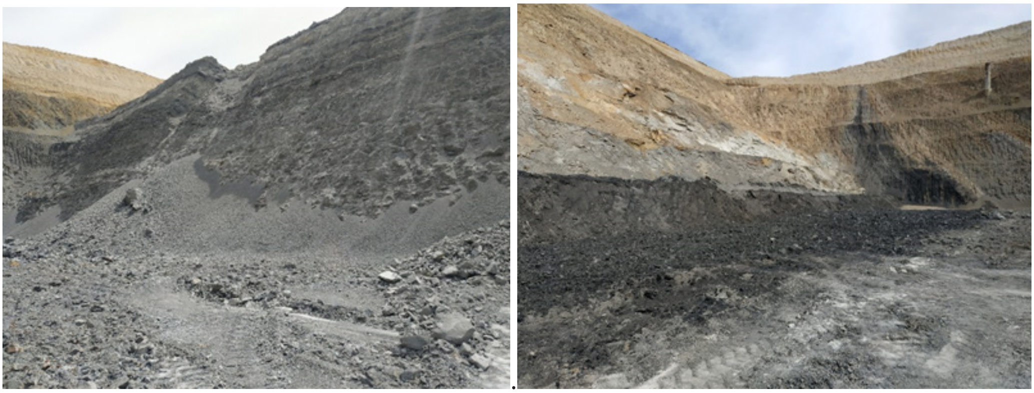


Figure 1 – A coal open pit

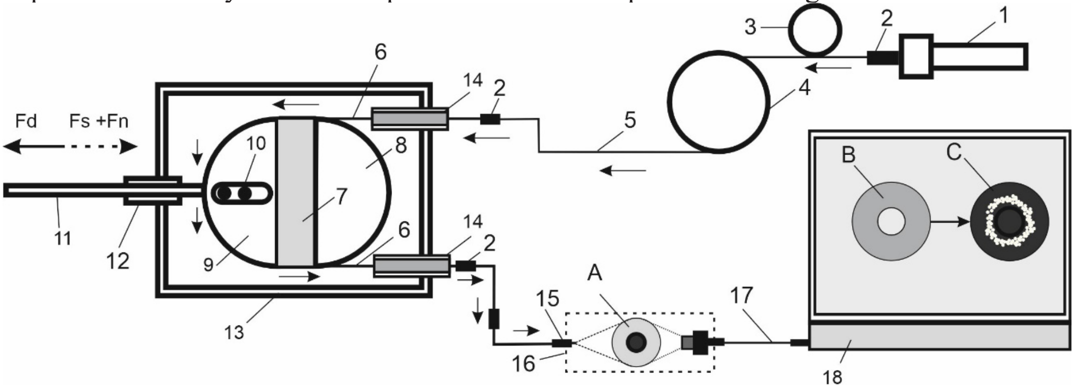
As an alternative to expensive and complex methods of geoscanning and the use of ground penetrating radar, it is proposed to use fiber optic sensors to create a safety monitoring system in quarries, and switching to the use of fiber-optic sensors as a simpler and less expensive means of control (Madi, 2022).

In foreign countries, studies are actively underway to develop fiber-optic displacement sensors (FODS), which play an important role in the mining industry, providing the reliable and accurate monitoring of the condition of rocks and structures (Buymistryuk, 2005). Their application helps improving the efficiency and safety of operations in this industry (Osório et all, 2017; Wang et al., 2016). FODS can accurately measure rock deformation and displacement in real time (Yiming et al., 2016). Chinese scientists T. Li, C. Wang, Y. Chao and Y. Ning have developed a safety system for underground mines that includes methane, pressure and temperature sensors (Liu et al., 2009). An integrated data fusion system was also developed to provide self-diagnosis and statistical analysis of sensor status, visual, audio and mobile text information (Liu et al., 2018; Su et al., 2016).

Displacement data helps identifying potential collapse zones, which allows taking preventive measures. Early detection of changes in rocks helps prevent accidents and collapses. The sensors developed by the authors can be installed in hard-to-reach places, providing continuous monitoring without the need for human intervention. Fiber-optic sensors are resistant to aggressive environments, moisture and temperature changes, which makes them ideal for the use in mining. They have a long service life and require minimal maintenance. The use of optical fiber reduces the cost of replacing and repairing equipment (Alkina et al., 2022). Fiber-optic sensors provide high measurement accuracy and are able to record even minor changes in the rock structure. The sensitivity of the sensors allows for a detailed analysis of the mine working state (Yurchenko et al., 2018; Mekhtiyev et al., 2023; Neshina et al., 2023).

Research methods

Experiments to study the developed sensors were carried out in laboratory conditions at the air temperatures from 22 °C to 23 °C with relative humidity within 60 %. The sensor used was quartz optical fiber type D/G.652 "Single Mode Corning SMF" with a core diameter of 9 microns and a cladding diameter of 125 microns. The quartz optical fiber is coated with a protective layer of acrylic varnish, which increases its thickness to 245 microns. Between the fiber-optic sensor and the laser, there is a 400 meter long optical fiber reel and a 30 meter long fiber optic patch cord. The connection of all the elements of the fiber-optic circuit is made using FC optical connectors. A diagram of the experiment to study the rock displacement sensor is presented in Figure 2.



1 – radiation source, 2 – optical connector, 3 – patch cord, 4 – coil, 5 – optical conductor, 6 – sensor, 7 – elastic element, 8, 9 – disks, 10 – guides, 11 – crossbar, 12 – bushing, 13 – crossbar, 14 – input coupling, 15 – output optical device, 16 – optical module,
17 – conductor, 18 – computer
Figure 2 – A diagram of the experiment to study the rock displacement sensor

A new monitoring system is proposed, which is based on the analysis of changes in the light signal passing through the optical fiber under mechanical influences on it, such as bending or pressure. The method proposed below does not use an optical interferometer or reflectometer, as well as the effect of Bragg gratings, since these methods have already been sufficiently studied. The method is based on analyzing changes in the size of the light spot using optical and digital technologies. This allows you to determine the amount of load on the optical fiber and determine the exact location where bending or stretching occurs. The signal processing system uses artificial intelligence algorithms to analyze changes in the light spot. This allows you to accurately determine the force of impact on the optical fiber. The laser beam from radiation source 1 passes through the sensor and enters the optical module. A semiconductor laser with a power of 30 mW and a wavelength of 650 nm, which operates in continuous mode, is used as a radiation source 1. The direction of movement of the light beam is indicated by solid arrows. Solid arrows show the direction of movement of optical radiation. Optical connectors 2 of the FC type are used for switching. In the experiment, the laser beam passed through fiber-optic patch cord 3 thirty meters long, and reel 4 with an optical fiber 400 meters long. Next, the beam passed through optical conductor 5 and hit the sensitive element of sensor 6. The sensitive element is made of a piece of single-mode optical fiber of the G.652 standard, which is wound into two parts of divided cylindrical coil 8 and 9 (half-disks), between them there is elastic element 7. The elastic element provides tension on the optical fiber wound on two parts of the divided cylindrical coil. Moving part 9 moves on two guides 10. Two half-disks 8 and 9 have the radius of 1 cm; the use of a smaller radius is unacceptable due to the critical radius, which leads to damage to the OF when it is bent. In this case, moving part 9 moves when crossbar 11 located in guide sleeve 12 moves. Half-disk 9 is rigidly connected to crossbar 11. The sensor has housing 13 that contains two input couplings 14. At the output of the sensor, output optical device 15 is installed to form an optical spot on the surface of the photomatrix located in optical module 16. The optical module contains a photomatrix and a graphics processor for converting the optical parameters of laser radiation into a digital signal. The optical module is connected using conductor 17 (USB cable). The data is processed using software installed on personal computer 18. Optical digital intellectual analysis is divided into three main phases A, B, C.

The A phase flows in the optical module, and the optical spot is transformed into a digital signal. When exposed to sensitive element 6, when crossbar 11 extends from sensor body 13, when an optical wave passes through element 6, its properties change. These changes are translated into changes in the pixel pattern displayed on the computer screen 18. The B phase is associated with the transformation of the positive images of the optical spot into negative ones, since the OF core is excluded from the analysis. The proposed sensor is an amplitude-type sensor, but unlike existing analogues, the change in the amplitude of additional losses formed in the OF shell is controlled. In the process of studies, it was established that under mechanical impact on the optical fiber (bending, torsion, stretching), part of the radiation leaves the core into the shell, which is the loss of the parental radiation power. It is recorded by the hardware-software complex installed on personal computer 18. The final C phase is associated with analyzing changes in the negative image of the optical spot and the formation of a pixel pattern. The further crossbar 11 slides along sleeve 12 located in housing 13, the more white pixels are formed on the computer screen. The crossbar creates a mechanical effect on the optical fiber through half-disk 9 with which it is rigidly connected; thus, the length of the optical fiber wound on two half-disks 8 and 9 changes. The lengthening of the optical fiber can be expressed through ΔL, the intensity ΔI and the paternal losses ΔA recorded by the photomatrix change. If a crack opens, the crossbar will move out, and the initial optical parameters will change when setting up the sensor. If one fixes body 13 on one benchmark, and the end of crossbar 13 on another benchmark and place these benchmarks above the growing crack, then one can record its growth. It is possible to give theoretical foundations that are associated with changing the distance between the fastening points by an amount ΔL, causing a joint displacement of the crossbar and the extension of the OF wound on half-disks 8 and 9 between which there is elastic damper 7. When exposed to the force caused by the elongation of the crossbar and its movement associated with the deformation of the massif and the opening of a crack, the tension force of the optical fibers and the tension force of the spring are formed. The relationship of forces can be represented as follows: $F_R = F_F + F_P$.

The tension force of optical fibers is as follows:

$$F_F = 2 \cdot n \cdot k_F \cdot l_s$$

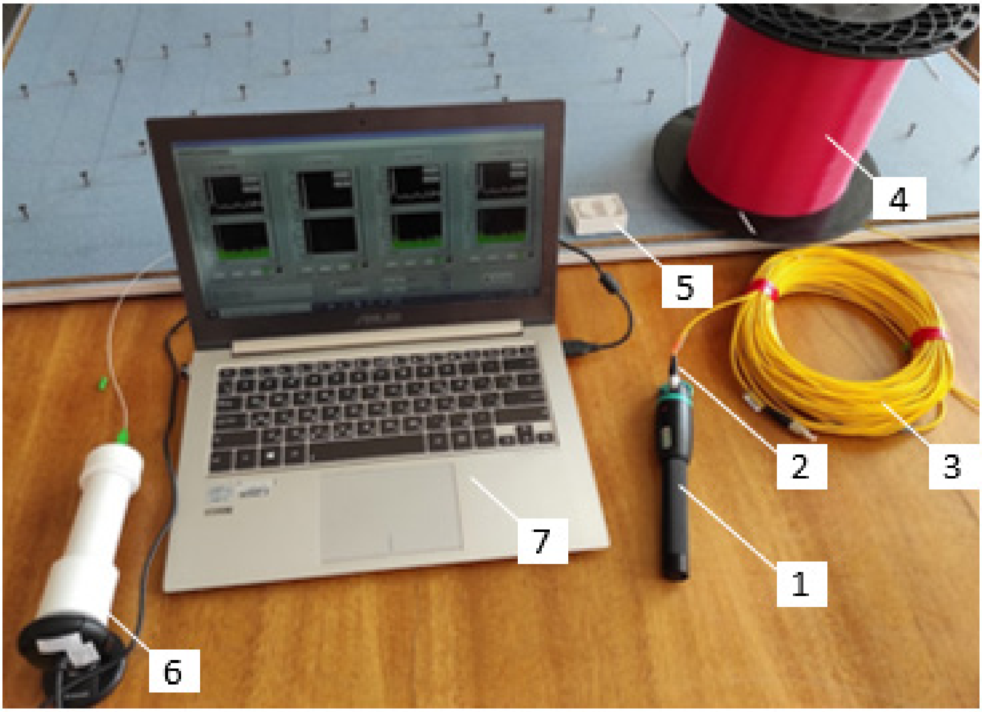
,

where is number of the OF windings,

k_F is the coefficient of the OF elasticity,

l_s is the OF elongation.

Figure 3 shows a laboratory sample of the FODS that was used in the research.



1 – laser; 2 – optical connectors of the FC type; 3 – fiber-optic patch cord; 4 – reel with optical fiber; 5 – fiber-optic sensor; 6 – optical module; 7 – personal computer.

Figure 3 – A laboratory sampl3e of the FODS

Results and discussion

Tests were carried out to determine the number of white pixels produced by mechanical stress (stretching) on an optical fiber. The results showed that stretching the optical fiber leads to a decrease in the optical power of the radiation passing through the sensitive element of the fiber-optic sensor at different values of the displacement ΔL. Figure 4 shows a graph showing the dependence of the number of white pixels on the offset value.

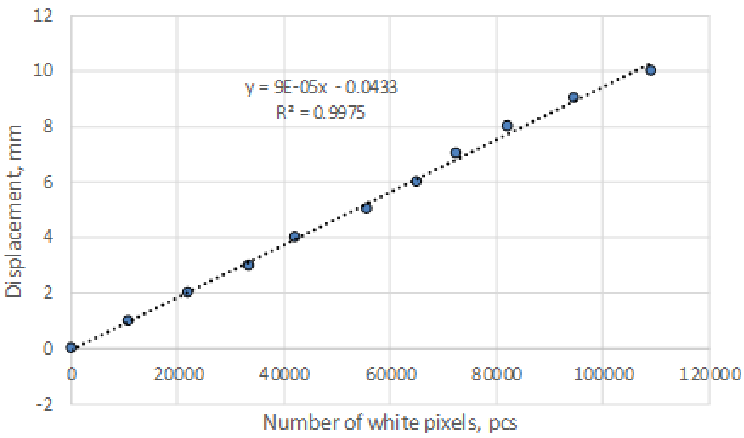
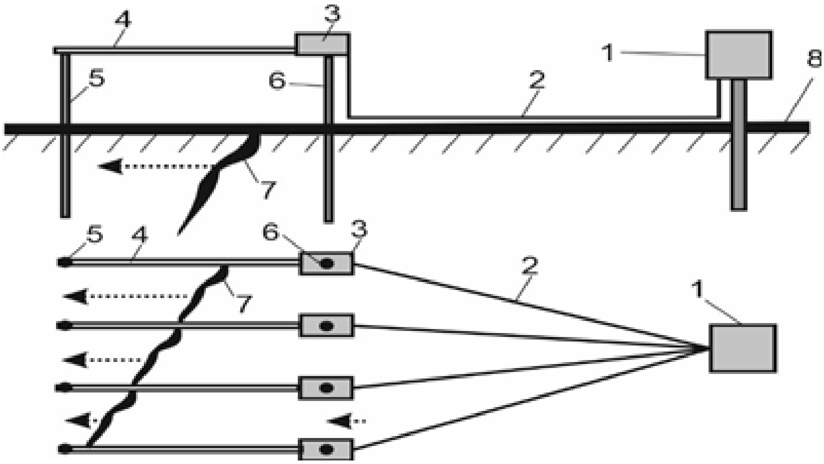


Figure 4 – Analysis of the relationship between the number of white pixels and the displacement value

To monitor the movement of rocks in quarries, it is proposed to use a scheme for placing FODS over a growing crack and a data processing system (Figure 5). Four to thirty two FODS are connected to data processing unit 1 with the use of optical patch cords 2 ten to thirty m long. The FODS is installed on fixed benchmark 6, and its sensing element is secured by crossbar 4 that is installed on movable benchmark 5. Benchmarks 5 and 6 are installed above growing crack 7 located in ground 8. When crack 7 expands, benchmark 5 moves and applies mechanical force to the system sensor through crossbar 4.



1 – data processing unit, 2 – fiber-optic conductors (patch cords), 3 – FODS, 4 – crossbar, 5 – movable benchmark, 6 – fixed benchmark, 7 – crack, 8 – soil

Figure 5 – A diagram of placing fiber-optic sensors over a growing crack and a data processing unit

Figure 6 shows photographs of the practical testing of a fiber-optic sensor installed above a growing crack. The photo shows the installed processing unit and the data processing module.

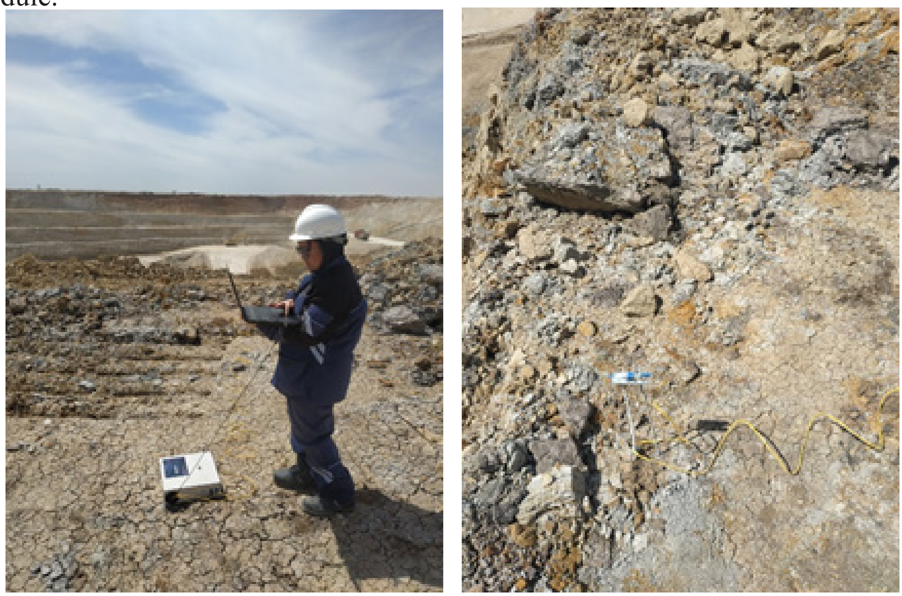


Figure 5 – Practical testing of a fiber-optic sensor installed over a growing crack

Conclusions

The developed system of optical-digital intelligent control of the open pit sides allows controlling rock displacement using a network of FODS. Changes can be monitored at multiple points simultaneously. The system uses artificial intelligence to analyze changes in the parameters of an optical wave passing through fiber-optic displacement sensors. The key feature of the proposed system is its ability to work in real time and transmit received data over long distances via radio channels to a control station. The FODS has a fairly simple design and is highly sensitive compared to electrical sensors. It also does not require power to operate.

The system provides the multi-channel processing of data from several sensors and allows making changes to settings online. The simplicity of the FODS design and its low cost make the system easy to use and allows for remote measurements with high accuracy. The system proved its performance during field tests at the Akzharyk Komir LLP.

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CONTENT

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