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Satbayev University

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ИЗВЕСТИЯ

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DEVELOPING A SENSOR FOR CONTROLLING THE PIT WALL DISPLACEMENT

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Abstract. The work deals with developing a pit wall displacement sensor. The analysis of the existing solutions has been carried out, their advantages and disadvantages have been given. An imitation laboratory bench has been presented with which use there were studied rock displacement sensors. The sensor has been developed on the basis of a new method of controlling additional optical losses. A source of coherent optical radiation with the wavelength of 1310 or 1550 nm has been used in the experiments. The sensor has a plastic case with two input adapters for optical connectors. One of them moves, the other does not move, and an elastic element is located between them. The light wave generated by the radiation source passes through the sensor and returns to the optical power meter. The sensor has been calibrated using a measuring scale with a division value of 1 mm. Depending on the distance between the ends of the optical fiber, the losses vary linearly. The use of a single-mode optical fiber for determining the displacement of the sides of a quarry is very promising, since the fiber-optic sensors developed on its basis have a sufficiently high accuracy, measurement speed, and good linearity of characteristics. The geotechnical parameters of the displacement of the sides of the open pit, which determine the danger of collapses that occur during the operation of technological equipment in the course of mining, are considered.
Keywords: fiber optic sensor, monitoring system, rock displacement, safety, optical fiber, deformation, safety

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КАРЬЕР БОРТТАРЫНЫҢ ЫҒЫСУЫН БАҚЫЛАЙТЫН ДАТЧИКТІ ӘЗІРЛЕУ

Аннотация. Бұл мақала карьер бортының сенсорын әзірлеуге арналған. Қолданыстағы шешімдердің жұмысына талдау жасалды, олардың артықшылықтары мен кемшіліктері келтірілді. Имитациялық зертханалық стенд ұсынылды, оның көмегімен тау жыныстарының орын ауыстыру сенсорына зерттеулер жүргізілді. Сенсор қосымша оптикалық шығындарды бақылаудың жаңа әдісі негізінде жасалған. Тәжірибелерде толқын ұзындығы 1310 немесе 1550 нм болатын когерентті оптикалық сәулелену көзі қолданылды. Сенсорда оптикалық қосқыштарды қосуға арналған екі кіріс адаптері бар пластикалық корпус бар. Біреуі қозғалады, екіншісі қозғалмайды және олардың арасында серпімді элемент бар. Сәулелену көзі тудыратын жарық толқыны сенсор арқылы өтіп, оптикалық қуат өлшегішіне оралады. Датчикті калибрлеу 1 мм бөлу бағасымен өлшеу шкаласы бойынша жүргізілді.оптикалық талшықтың ұштары арасындағы қашықтыққа байланысты шығындар сызықтық заңға сәйкес өзгереді. Карьерлердің бүйірлік жылжуын анықтау үшін бір режимді оптикалық талшықты пайдалану өте перспективалы, өйткені оның негізінде жасалған талшықты-оптикалық датчиктер өте жоғары дәлдікке, өлшеу жылдамдығына ие және өнімділіктің жақсы сызықтығына ие. Пайдалы қазбаларды өндіру процесінде технологиялық жабдықтың жұмысы кезінде пайда болатын құлау қаупін анықтайтын Карьер бортының жылжуының геотехникалық параметрлері қарастырылады.

Түйін сөздер: талшықты-оптикалық датчик, бақылау жүйесі, карьер борттарының ығысуы, қауіпсіздік, оптикалық талшық, деформация, қауіпсіздік

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РАЗРАБОТКА ДАТЧИКА КОНТРОЛЯ СМЕЩЕНИЯ БОРТОВ КАРЬЕРОВ

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Аннотация. Данная статья посвящена разработке датчика смещения бортов карьера. Проведен анализ работ существующих решений, приведены их плюсы и недостатки. Представлен имитационный лабораторный стенд, с помощью которого были проведены исследования датчика смещения горных пород. Датчик разработан на основе нового метода контроля дополнительных оптических потерь. В экспериментах использовался источник когерентного оптического излучения с длиной волны 1310 или 1550 нм. Датчик имеет пластиковый корпус с двумя входными адаптерами для подключения оптических коннекторов. Один из который двигается, другой — нет, а между ними расположен упругий элемент. Световая волна, генерируемая источником излучения, проходит через датчик и возвращается к измерителю оптической мощности. Калибровка датчика выполнялась при помощи измерительной шкалы с ценой деления 1 мм. В зависимости от расстояния между торцами оптического волокна потери изменяются по линейному закону. Использование одномодового оптического волокна для идентификации смещения бортов карьеров является весьма перспективным, так как разработанные на его основе волоконно-оптические датчики обладают достаточно высокой точностью, скоростью измерения и имеют хорошую линейность характеристик. Рассмотрены геотехнические параметры смещения бортов карьера, определяющие опасность обрушений, возникающих при работе технологического оборудования в процессе добычи полезного ископаемого.

Ключевые слова: волоконно-оптический датчик, система мониторинга, смещение бортов карьера, безопасность, оптическое волокно, деформация, безопасность

Introduction

The pits are characterized by high labor productivity, low production costs, integrity of mining, optimal and relatively safe working conditions. Full development and extraction of minerals should be accompanied by the minimum amount of overburden. Vice versa, it is possible to achieve the minimum cover layer in a pit only when the problem of ensuring stability of the pit walls is solved.

The advantages of fiber-optic sensors and technologies in relation to stability of open pit walls are as follows: the use of these systems to control geotechnical parameters, which make it possible to ensure the required level of safety in mining operations with minimal energy consumption; no need for multiple power supplies; explosion hazard to ensure that the optical fiber must not cause sparks; high corrosion resistance; they eliminate the effects of electromagnetic interference; optical fiber sensors are more sensitive and stable, easy to reuse in communication lines. Unlike traditional instrumental observations and new methods (scanning the pit walls), fiber-optic sensors have a number of significant advantages in terms of measurement speed and are insensitive to many external effects. At the same time, energy consumption is ten times lower than the information transmission over the air or a copper cable.

At present, the development of coal mines and quarries is characterized by modernization, the acquisition of new mining technologies, the use of new technological solutions, which lead to improving mining operations. In this case, open pit mining will play a special role in reliably explaining, presenting and monitoring the stability status of pit walls.

The modern scale of mining requires in-depth research and constant monitoring of geotechnical processes occurring on the pit walls during the pit operation. It is desirable to equip every pit with an automated system for monitoring the wall stability.

Under the conditions of open pit mining, geomechanical processes (Nizametdinov et al., 2015: 1; Reed et al., 2015: 2) are understood to mean various kinds of deformations in the pit. Many scientists have been studying the deformations of the pit walls and their classification (Chotchayev, 2016: 3; Buymistryuk, 2011: 4; Baibatsha et al. ,2020: 5; Mekhtiev et al., 2021: 6).

Relevance and problem definition

The pit wall stability is determined by the power state of the rocks. The deformation conditions and the stress state of the near-edge massif are made up of a combination of various factors, which are divided into two categories: natural and mining. Natural factors include the climate (air temperature, precipitation, wind potential, temperature conditions of rocks); geology (composition, structure, condition and nature of rocks); hydrogeology (presence of surface waters and aquifers, flood contact and structural disturbances). Mining factors are the method of developing the site, the development complex, the method of crushing the rock massif of the pit, the method of dumping layers and geometric parameters.

The most significant factors that affect pit wall stability are physical and mechanical properties of rocks and contacts with rocks; the structure and design characteristics of the array of devices; geometric parameters of the slope; stress-strain state of the array of devices; The first two factors of production technology are natural and inherent factors of this particular field. They cannot be changed and must be studied and taken into account when calculating the stability of the side. The third and fourth factors are related to the mining technology used and must be determined in the process of solving the problem of ensuring the stability of the pit wall.

A number of Kazakhstan and foreign scientists are engaged in studying the impact of drilling and blasting on the made of rock and semi-rock pit slope stability (Buimistryuk, 2013: 7; Volchikhin, 2001: 8; Kamenev et al., 2014: 9; Liu et al., 2013: 10; Yiming et al., 2016: 11; Kim et al., 2015: 12; Wu et al., 2011: 13; Mekhtiev et al., 2020: 14). However, due to the diversity of the mining and geological features of the deposits and the mining conditions developed in the pits, the solutions proposed in these works cannot always be used in the other pits. In addition, all the works on this issue are aimed at studying the effect of large-scale explosions on the state of non-working (stationary) pit walls stability, as well as the effect of pit walls on the profile of the production limit.

Analyzing the existing methods of calculating open pit slopes stability, it should be noted that quite reliable calculation schemes have been developed that correspond to various mining, geological and mining conditions prevailing in the field. Various geological characteristics of the developed fields exclude the existence of a universal solution to this problem. The work of scientists from different countries has attracted attention in the field of deformation measurement of the underground infrastructure, including that in the mining industry (Kamenev et al., 2014: 9; Liu et al., 2013: 10; Yiming et al., 2016: 11; Kim et al., 2015: 12; Wu et al., 2011: 13; Mekhtiev et al., 2020: 14; Chaulya et al., 2016: 15), where the measurement of deformation over the almost infinite length allows fixing the deformation field caused by underground work in the excavation deformation field.

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

Since 2006, in the mining industry there has been introduced the optical fiber technology for strain detection (Nizametdinov et al., 2015: 1; Reed et al., 2015: 2). The world manufacturers of fiber-optic sensors are the Siemens, the ABB, the Rockettes, the Waterford, the Bedhess, the Halliburton, the Schlumberger companies, as well as the Russian companies such as the Intel-Systems, the Omega, the Optolink. The analysis of the world experience in the development of fiber optic sensors in Western Europe and the USA, as well as the developments of scientists from the CIS countries, shows that the work is aimed at improving and developing various fiber optic technologies for controlling, monitoring and measuring (Buimistryuk, 2013: 7; Volchikhin, 2001: 8; Kamenev et al., 2014: 9; Liu et al., 2013: 10; Yiming et al., 2016: 11; Kim et al., 2015: 12; Wu et al., 2011: 13; Mekhtiev et al., 2020: 14). The issues related to the production of optical fiber are considered. The studies are being carried out on the use of fiber optic sensors to develop an internal fiber optic network in order to collect information in conditions of increased risk of sparking and explosion hazards. In particular, a lot of work (Yiming et al., 2016: 11; Kim et al., 2015: 12; Wu et al., 2011: 13) deals with the use of fiber optic sensors as a promising tool for monitoring, measuring and controlling parameters in national defense, aerospace, aviation, transport, oil and gas industries, as well as in construction and medicine.

The development of a hardware-software complex for security control based on the use of optical fiber will make it possible to abandon the use of equipment for measuring technical parameters and switch to the use of fiber-optic sensors. Fiber optic sensors are widely used in various industries around the world. For example, an optical fiber sensor was used for current measurement, as well as in buildings and structures. The optical fiber technology was also introduced in the mining industry for strain detection, detection of underground gases such as methane and monitoring the underground environment (Volchikhin, 2001: 8; Kamenev et al., 2014: 9; Liu et al., 2013: 10; Yiming et al., 2016: 11; Kim et al., 2015: 12; Wu et al., 2011: 13). Chinese scientists T. Li, Ch. Wang, Yu. Chao, and Yu. Ning developed an integrated hazard detection system consisting of methane sensors, pressure sensors, and temperature sensors installed in underground mines (Wang et al., 2016: 16; Manbetova et al., 2021: 21; Alkina et al., 2017: 17). An integrated data fusion system was also developed to provide self-diagnosis and statistical analysis of the state of sensors, visual, sound and mobile text information. Experimental studies were very successful, and then the authors began to develop a method of determining seismic energy.

At present, the development of pits is characterized by the improvement of new processes and acquisition of new tools, the latest technological solutions in the extraction of mineral deposits for smooth and safe operation of mining enterprises. In this regard, a special role is assigned to reliable justification and ensuring safety in monitoring the open pit walls stability.

The proposed sensor is based on the previously proposed principle of pressure measurement using the method of controlling additional losses in the optical fiber under mechanical action. One can be familiarized with the patent (Chaulya et al., 2016: 15; Orazbayeva et al., 2022: 20). The basis of the proposed method is assessing additional losses in an optical fiber during its deformation, which use was considered in (Lanciano et al., 2020: 18; Orazbayeva et al., 2022: 22; Yakubova et al., 2016: 19). The principle of operation and design of a fiber-optic sensor for monitoring rock pressure in underground workings are given in (Yugay et al., 2020: 20). The considered sensor has basically an optical fiber of the G 652 standard.

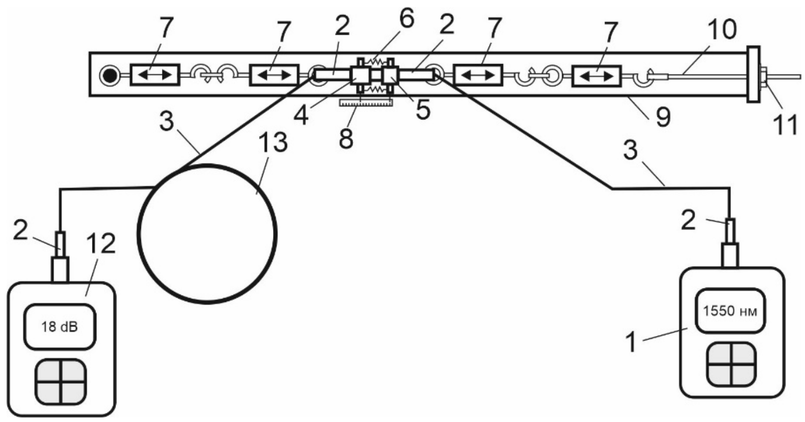
Developing a fiber optic rock displacement sensor and a measurement system

For practical implementation of the studies carried out, to test the scientific hypothesis put forward about the use of optical fiber to build a complex for monitoring wall displacements, an imitation laboratory bench has been developed. Figure 1 shows a laboratory sample of a fiber optic pit wall displacement sensor. The source of optical radiation is SmartPocket OLS-34/35/36 with built-in Auto-λ and Multi-λ options, SmartPocket OLP-38, which can automatically measure the power level and insertion loss in a single-mode and multimode optical cable. The connection to the optical fiber is made through a universal UPP 2.5 mm adapter and optical connectors of the SC type.

Figure 1 – Laboratory sample of a fiber optic pit wall displacement sensor

When the ends of the ferrules into which the optical fiber is inserted, diverge up to 15 mm, the measurement range can be extended up to 100 mm, if needed. So far, there are limitations associated with the parameters of the used ferrules, which edged the ends of the OF and the tube in which the ferrules move. One can connect several sensors in series or use a transmission mechanism to increase the divergence distance of the OF. When the ends of the fiber move away from each other, additional losses increase, which are recorded by an optical wattmeter. The farther the optical fiber ends diverge from each other, the greater the level of additional losses and loss of optical power. The scheme of the laboratory bench is shown in Figure 2.

A source of coherent optical radiation with the wavelength of 1310 or 1550 nm has been used in the experiments. The sensor has a plastic case, with two input adapters for optical connectors, one of which moves, the other does not move, and an elastic element is located between them. The light wave generated by the radiation source passes through the sensor and returns to the optical power meter.



1 - radiation source of the invisible range 1550 nm; 2 - optical SC convector; 3 – fiber optic patch cord; 4 - fixed part of the fiber-optic displacement sensor; 5 – moving part of the fiber-optic displacement sensor; 6 - spring; television matrix, 7 - tension clutch; 8 - displacement report scale; 9 - base; 10 - pin for adjusting the position of the moving part of the sensor; 11 - nut; 12 – optical power meter; 13 - a loop of fiber-optic patch cord 30 meters long

Figure 2 - The experiment design

The results of the experiments are presented as a graph of the optical losses dependence on the value of displacements (Figure 3).

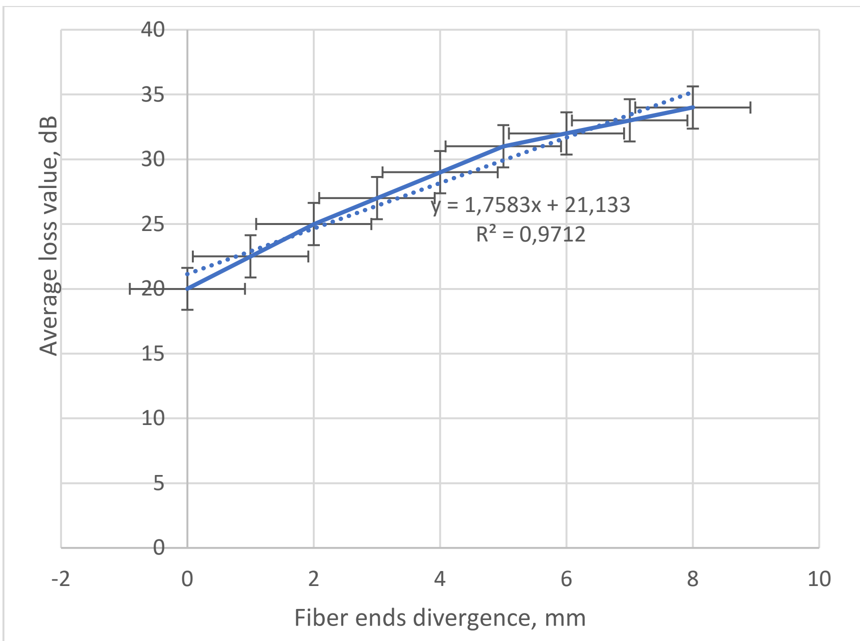
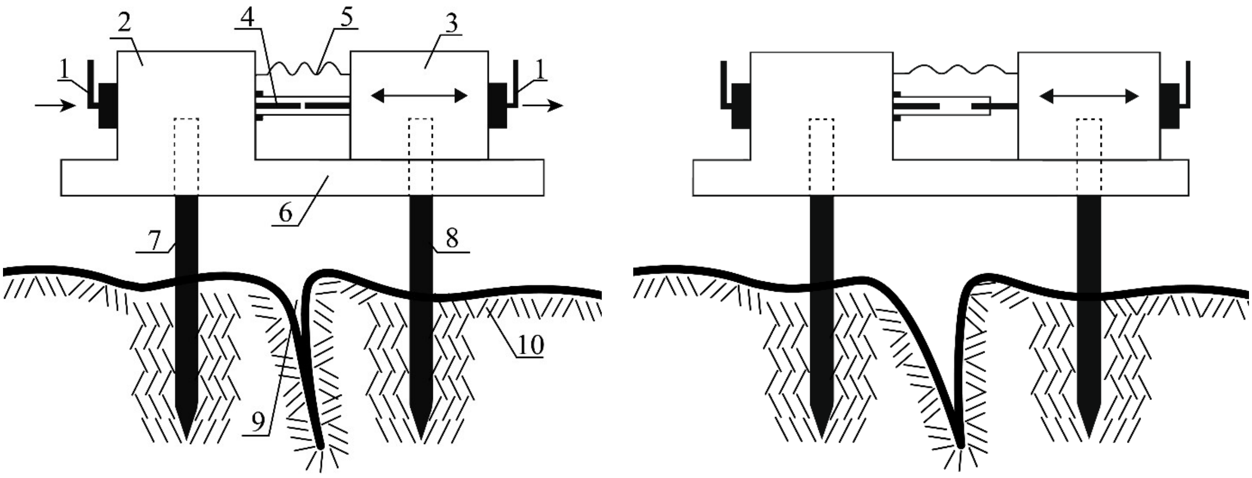


Figure 3 - Graph of the optical losses dependence on the value of displacements

The sensor was calibrated using a measuring scale with a division value of 1 mm. Depending on the distance between the ends of the optical fiber, the losses vary linearly. The considered sensor has basically an optical fiber of the G 652 standard.

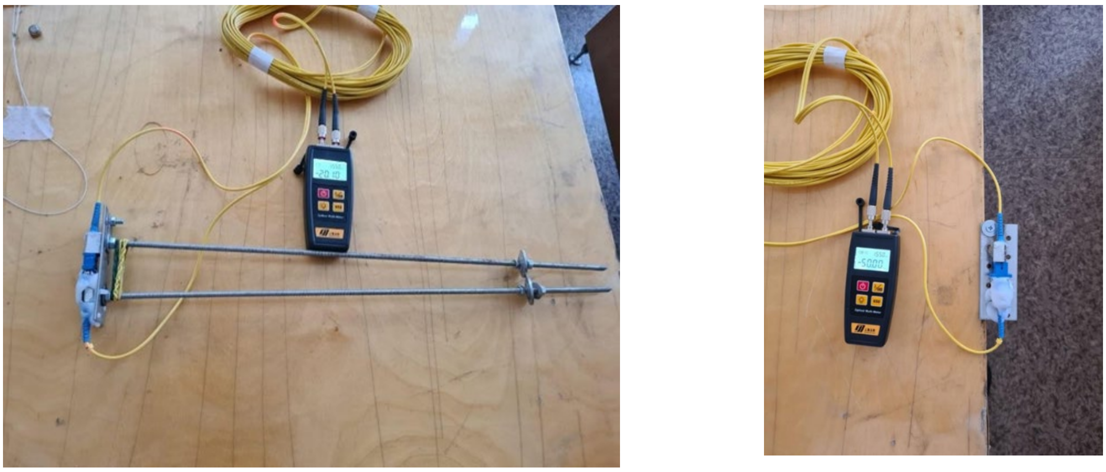
At the present time, the control of the displacement of the walls is performed with the help of benchmarks, as well as visual and instrumental observations with participation of mine surveyors. The accuracy of control is affected by the human factor; it is also necessary to take into account the suddenness of changes in rock pressure in certain areas and the formation of emergency zones of collapse. Long-term monitoring changes in rock pressure shows a rather acute problem of sudden collapse of the open pit walls that leads to a danger to the life of personnel, equipment and significant financial costs. Therefore, there is a need to develop a hardware-software complex for monitoring the pit wall stability using fiber-optic sensors, which will provide more reliable data and remote monitoring in real time, preventing cases of sudden collapse of the edge massif.

Figure 4a shows the block diagrams of the sensor in its normal position in the absence of rock movement. Figure 4b shows the situation when there are displacements of the pit wall rocks and crack opening.



a) at the initial moment of crack opening; b) the process of crack opening
Figure 4 - Sensor in normal and offset position:
1 - optical fiber, 2 - fixed connector, 3 - movable connector, 4 - ferrule, 5 - spring, 6 - base,
7 - fixed reference point, 8 - movable reference point, 9 - crack, 10 - soil

Using the results of the laboratory tests, a prototype sensor has been developed (see Figure 5).



a) in horizontal position b) in vertical position

Figure 5–A prototype of the sensor

The sensitivity of the developed sensor is several times higher than that of the applied mechanical reference stations. At the same time, it should be taken into account that the operator controls the parameters of the reference station visually and it is possible to notice the benchmark displacement by at least 5 mm, which is the division price, while the sensor is capable of capturing changes of 1 mm, the measurements are made remotely in real time. If needed, the measuring range of the sensor can be 0–100 mm. The sensitivity threshold is 1 mm. The effectiveness of the proposed control system lies in the fact that this system is able to control the initial displacements and to fix the initial moment of crack growth, which is important for making decisions on controlling the pit wall stability.

Conclusions

The work is aimed at solving production problems associated with improving the safety of mining operations at the Kenzhem pit of the AC Altynalmas JSC. The use of the proposed sensor will make it possible to control remotely stability of the pit walls in real time. The obtained results of laboratory studies allow stating that the developed sensor has a fairly good linearity of characteristics and low power consumption, and is also capable of operating at the distance of up to 30 km with a radiation source power of lower than one watt, which is much lower compared to the existing traditional electrical measuring systems. The development of the own circuit solutions and a hardware-software complex, as well as the use of standard telecommunications equipment, radiation sources, photodetectors, connectors, can significantly reduce the cost of the sensor as a whole, which can ensure its practical implementation.

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