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## Research of fiber-optic displacement sensors

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**Abstract.** Research on fiber-optic displacement sensors in quarries is the main cause of the collapse of the sides of the quarry. To ensure safety and constant monitoring during the work at the quarry, sharpened fiber-optic sensors are used. Fiber-optic sensors and control cables of the communication line are made on the basis of single-mode optical fibers, which makes it possible to measure deformations and displacements of the mountain range at distances of 30-50 km with high accuracy. Optical fiber of the ITU-T G. 652.D standard is used to create fiber-optic pressure sensors (FOS). All tests were carried out in the laboratory. This article is a sample for studying the entire process of deformation and displacement of the mountain range. In the end, the results of the study will help to optimize the work at the quarry and prevent accidents

### 1. Introduction

Open-pit coal mining is characterized by an increase in the capacity and depth of coal mines, modernization of technological processes, taking into account the features of the relevant measures, which are one of the main sore points during operational work at the quarry. In this regard, the control and monitoring of the stability of the sides and berm in the quarry is an urgent scientific and practical problem. The analysis in works [1–3] shows that there is a problem and the solution of this issue cannot be approached one-sidedly, it is necessary to use various methods. This requires a technology focused on the development of sensors using optical fibers. The work is aimed at developing sensors, as there is a problem with the stability of the sides, the berm of the quarry. In, the basic principle of setting up data processing experiments and constructing a mathematical model and apparatus is taken. In [4], the authors conducted a series of experiments on modeling fiber-optic sensors and using them to diagnose the stress-strain state of lifting machines. Currently, various methods are used, which in turn are also effective, but the question arises of developing a new method based on fiber-optic technology, which has the advantages previously described in [5], where experiments are conducted to study additional losses during mechanical action on an optical fiber. The paper [6] describes research on the development of the physical basis for creating sensors and a physical and mathematical model of the optical signal parameter control system. Also, the authors [7] propose a system for monitoring the state of fiber-optic communication lines, and some functional features of its operation will be used in further work on creating a system for monitoring mixing of quarry sides using fiber-optic sensors. From this work, you can use some data processing algorithms and methods for transmitting information. The system proposed by the authors allows collecting information from sensors,

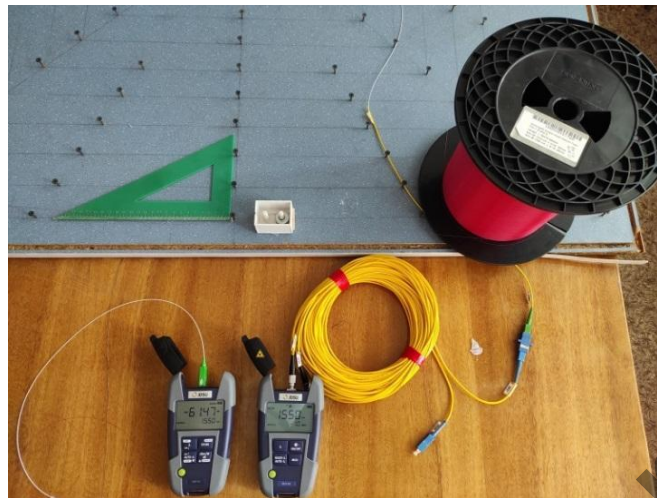


processing it, and making various decisions on triggering a warning alarm. In addition, a scientific analysis of similar works by foreign authors who work with optical fiber and develop fiber-optic sensors was performed. Scientists Liu X, Wang C, Liu T, Wei Y, Lv J produced a new water pressure sensor based on a fiber Bragg grating, where the applicability of the sensor for monitoring water pressure was confirmed [8]. In 2011, scientists Kumar Atul, Kumar Dheeraj, Singh U., Gupta P S., Shankar Gauri illustrated the development of a system for continuous monitoring of blood pressure and closing the support with progressive advancement of the face in lava workings. Illustrated example of working long wall to assess the effectiveness of the monitoring system evaluating the performance of bolting for a more secure and smooth operation of roof supports in these mines in various geological and mining conditions [9]. The work Madjdabadi B, Valley B, Dusseault M B and Kaiser P K attracts attention in the field of strain measurement in underground infrastructure, including the mining industry [10], where strain measurement over an almost unlimited length makes it possible to record the strain field caused by underground workings outside the excavation damage zone. The potential benefit of such monitoring of the strain field is the strain of the continuum under tension, compression, or shear, or as a fracture strain due to local shear or expansion of inhomogeneities. In 2016, scientists Yiming Zhao, Nong Zhang and Guangyao Si in their work [11] showed the development and experiments on a new system for monitoring safety at a quarry based on the fiber Bragg grating material. Compared to traditional monitoring equipment, the developed new monitoring system has the advantages of providing accurate, reliable and continuous online monitoring of quarry activities. Scientists Tao Hu, Gongyu Hou and Zixiang Li shared their work with the results of tests where high-strength optical fiber made of stainless steel has high deformation transmission characteristics, which allows it to be connected to a concrete anchor with uniform deformation. This demonstrates the possibility of using fiber for theoretical and experimental monitoring of reservoir movement [12]. Later, other scientists Chiara of Lanciano, Riccardo Salvini in their work [13] dealt with the issue of safety at work, checking and tracking the conditions of stability of the mountain range, which shows the results of an innovative method of analysis based on a combination of distributed fiber-optic sensors, digital photogrammetry using unmanned aerial vehicles, topographic and geotechnical monitoring systems. In addition, the study used the methods of analysis proposed by Kazakh and Russian authors [14–16]. And the purpose of this work is to create sensors for monitoring, measuring and monitoring the stability of the sides, berm of the quarry using fiber-optic sensors.

## 2. The measurement technique

For practical implementation of the research, to test the scientific hypothesis about the use of optical fiber to build a system for measuring the displacement of the sides, a simulation laboratory stand was developed, which is shown in Figure 1.

Measurements are made based on the method of determining additional losses in the optical fiber under mechanical action. As a measuring device, the VIAVI optical power meter (JDSU) SmartPocket OLP-38 is used, operating in the dynamic range from -60 to +26 dB, with a wavelength range of 780-1650 nm. The SmartPocket OLS-34/35/36 was used as the optical radiation source. The connection to the optical fiber was made via a universal UPP 2.5 mm adapter and SC type optical connectors. The measuring body is a sensor based on two rollers located in the housing separated from each other by an elastic element. Corning SMF 9/125 microns quartz single-mode optical fiber (ITU-T G. 652.D standard) is used as a fiber-optic sensor. The optical fiber has a primary coating of 245 microns. Installed coils with an optical fiber length of 2.00 km made using a standard patch cord length of 20 meters, edged on both sides with SC connectors. All experiments were conducted under laboratory conditions at an air temperature from 22 to 23 °C with a relative humidity of 60%.

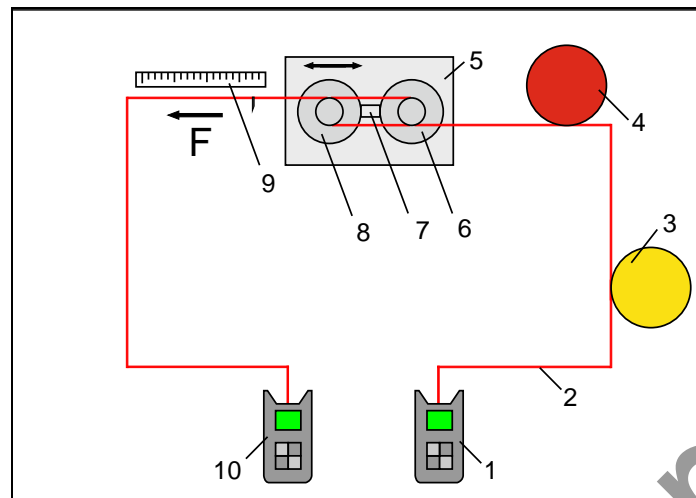


**Figure 1.** General view of the simulation laboratory stand.

The measurement method is based on the estimation of additional losses that occur in the optical fiber when it is bent. A light wave is generated from a coherent optical radiation source with a wavelength of 1310 or 1550 nm. The light source is a semiconductor laser that connects to a standard telecommunications patch cord and coil. The fiber-optic sensor has a housing in which two rollers are placed. One of the rollers is stationary, and the other roller is movable. There is an elastic element between the rollers. At the output of the housing, light waves pass through the measuring system, after which the light wave enters the optical wattmeter.

A simulation laboratory stand was developed, where a SmartPocket OLS-34/35/36 laser with wavelengths of 1310 or 1550 nm was used as a light source, a Corning SMF 9/125 microns quartz single-mode optical fiber, patch cords for connection, and a 2.00 km long optical fiber coil were used. The sensor itself is placed in a housing made of white plastic based on two rollers located in the housing, separated from each other by an elastic element. A ruler serves as a measuring system. The measurements were performed with the SmartPocket OLP-38 optical wattmeter, which operates in the dynamic range from -60 to +26 dB, with a wavelength range of 780–1650 nm.

A light wave is generated from a coherent optical radiation source with a wavelength of 1310 or 1550 nm. The light source is a semiconductor laser that connects to a standard telecommunications patch cord and coil. The fiber-optic sensor has a housing in which two rollers are placed. One of the rollers is stationary, and the other roller is movable. There is an elastic element between the rollers. At the output of the housing, light waves pass through the measuring system, after which the light wave enters the optical wattmeter. The measurement method consists in the fact that there was a fiber tension, the count was made along the entire length of the measuring system (ruler). Depending on the elongation, the losses changed, i.e. the task of the sensor is to measure additional losses in the optical fiber during mechanical action on it. The radiation source generates a light wave of 1310 nm, and the optical power meter detects the attenuation of the additional loss signal. These values are used for recalculation related to the offset. The measurement scheme of the simulation laboratory stand is shown in Figure 2.



**Figure 2.** Diagram of a simulation laboratory stand: 1 – light source, 2 – optical fiber, 3 – patch cord, 4 – coil, 5 – sensor housing, 6 – fixed roller, 7 – elastic element, 8 – movable roller, 9 – measuring system, 10 – optical wattmeter.

### 3. Results of the conducted experiments

This paper presents the use of optical fiber to build a system for measuring the displacement of the sides. A fiber-optic sensor using a single-mode optical fiber to control offsets with a change in sensitivity and a reduced influence of temperature interference leading to zero drift is determined by the formula

$$\Delta I(t) = 2I \sin(\Delta\Psi + \Delta\Psi(t)), \tag{1}$$

where  $\Delta I(t)$  – the change in the intensity;  $\Delta\Psi$  – initial and random phase difference of light waves;  $\Delta\Psi(t)$  – the phase difference associated with changes in the propagation conditions in the optical fiber under external mechanical action and fiber displacement is a small correction against the background of the first term.

When offset, a measurement of the distance between the points of attachment of the optical fiber  $\Delta L$  occurs, which is equal to the change in the length of the light guide

$$I(t) = 2I \sin(\Delta L \cdot \alpha + \Delta\Psi(t)), \tag{2}$$

$\alpha$  – mode propagation constant of a fiber light guide.

The physical bases associated with a change in the distance between the anchor points by a value of  $\Delta L$ , cause joint displacement and elongation of the fiber-optic sensor. When exposed to the tension  $F_R$ , caused by its displacement, associated with the displacement, the tension force of the optical fibers  $F_R$  and the tension force of the spring  $F_P$ .  $F_R = F_R + F_P$ .

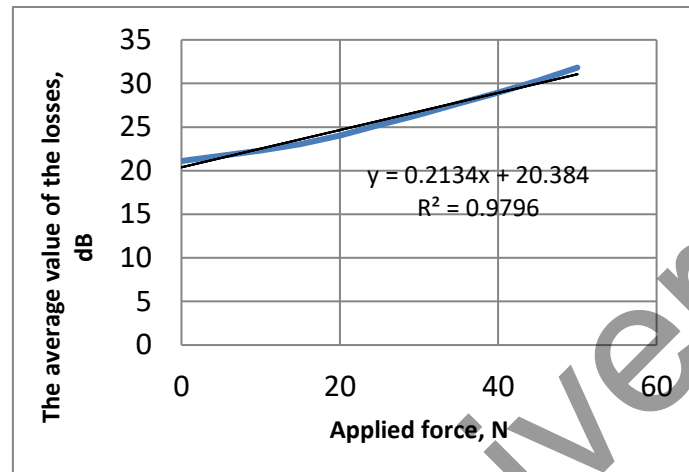
The force of the tension of optical fibres  $F_F = 2 \cdot n \cdot kF \cdot ls$ ,

where  $n$  – number of turns of optical fiber,  $kF$  – the coefficient of elasticity of the optical fiber,  $ls$  – the elongation of the optical fiber.

The obtained results are explained by the inverse relationship between the value of the elasticity coefficient: the greater the number of turns of the OM, the lower the elasticity coefficient. Experiments were carried out to determine additional power losses of an optical signal passing through a fiber-optic sensor at different displacements. The displacement values were measured repeatedly, followed by processing the experimental data and averaging the obtained values using a ruler. The results of the experiments are represented by a graph of the dependence of optical losses on the offset value, which is shown in Figure 3.

The results of the experiments were processed taking into account the lowest value of the Akaike information criterion, and the best option was chosen by a second-degree approximation, at which the coefficient of determination  $R^2=0.9683$ . As a result, the laboratory sample of the fiber-optic sensor

showed a fairly high linearity, changing parameters. In addition, the results suggest that it can definitely be a sensor with high measurement accuracy. In the future, it is possible to use a laboratory sensor to work out a sensor for monitoring the displacement of the sides of the quarry. Based on the measurement results, an absolute error of 2.486, a relative error of 9.702, and a student coefficient of 2.228, with a confidence interval of 0.95, were calculated.



**Figure 3.** Graph of the dependence of optical losses on the offset value.

#### 4. Conclusions

The results of laboratory experiments have proved that the optical fiber can be used as a sensor, has good linearity, and can be used to control the stability of the sides of the quarry. Laboratory research is aimed at developing sensors using fiber-optic sensors that allow real-time remote monitoring of the stability of the sides of quarries. The results obtained during laboratory studies suggest that the developed fiber-optic sensor has a fairly good linearity of characteristics and low power consumption at a distance of 30-50 km compared to electrical measuring systems.

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