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HARDWARE-SOFTWARE COMPLEX FOR IDENTIFICATION OF ROCK DISPLACEMENT IN PITS

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Abstract. This article deals with the development of a hardware-software complex for identifying the pit rock displacement that allows measuring continuously several parameters and notifying in a timely manner the personnel of mining enterprises that carry out development by underground and surface methods. The software included in the hardware-software complex is easy to use and allows making changes to the information interface. The hardware-software complex collects, processes and analyzes the data from fiber-optic sensors that control the geotechnical state of the adjacent rock massif. The hardware-software complex is connected to fiber-optic sensors using optical conductors, thus eliminating the use of an expensive copper cable. Fiber optic sensors are intrinsically safe and explosion-proof, they also have a high immunity to electromagnetic interference. The hardware-software complex with fiber-optic sensors makes it possible to implement the monitoring of the pit workings geotechnical state.

The hardware-software complex principle of operation is based on the comparison of apertures and the intensity of light spots using a high-resolution photodetector. It has been established that the diffraction spots and their pixel pattern do not change in the absence of displacement of the adjacent rock massif. In the event of a displacement, the light wave passing through the fiber-optic sensors changes its properties, the parameters of the light spot change accordingly; after processing the data, the hardware-software complex gives a numerical value of the displacement.

Keywords: pit, displacement, rock, adjacent rock massif, hardware and software complex, fiber-optic sensor, geotechnical condition

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КАРЬЕРЛЕРДІҢ ТАУ ЖЫНЫСТАРЫНЫҢ ЖЫЛЖУЫН СӘЙКЕСТЕНДІРУДІҢ АППАРАТТЫҚ-БАҒДАРЛАМАЛЫҚ КЕШЕНІ

Аннотация. Бұл мақала Карьерлердің тау жыныстарының жылжуын сәйкестендірудің аппараттық-бағдарламалық кешенін әзірлеу мәселесіне арналған, ол бірнеше параметрлерді үздіксіз өлшеуге және жер асты және жер үсті әдістерімен игеруді жүзеге асыратын тау-кен кәсіпорындарының қызметкерлеріне уақтылы хабарлауға мүмкіндік береді. Аппараттық-бағдарламалық кешеннің құрамына кіретін бағдарламаны қамтамасыз етуді пайдалану оңай және ақпараттық интерфейске өзгерістер енгізуге мүмкіндік береді. Аппараттық-бағдарламалық кешен аспаптық массивтің геотехникалық жай-күйін бақылайтын талшықты-оптикалық датчиктерден деректерді жинауды, өңдеуді және талдауды жүзеге асырады. Аппараттық-бағдарламалық кешен оптикалық өткізгіштердің көмегімен талшықты-оптикалық датчиктерге қосылады, осылайша қымбат мыс кабелін пайдалануға жол берілмейді. Талшықты-оптикалық датчиктер ұшқын өткізбейтін және жарылысқа төзімді, сонымен қатар электромагниттік кедергілерге төзімділігі жоғары. Талшықты-оптикалық датчиктері бар аппараттық-бағдарламалық кешен Карьерлердің тау-кен қазбаларының геотехникалық жай-күйіне мониторинг жүргізуге мүмкіндік береді. Аппараттық-бағдарламалық кешеннің жұмыс принципі жоғары ажыратымдылықтағы фотодетектордың көмегімен диафрагмалар мен жарық дақтарының қарқындылығын салыстыруға негізделген. Дифракциялық дақтар мен олардың пиксельдік үлгісі аспаптық массивтің тау жыныстарының орын ауыстыруы болмаған кезде өзгермейтіні, орын ауыстыру пайда болған кезде талшықты-оптикалық датчиктер арқылы өтетін жарық толқыны өзінің қасиеттерін өзгертетіні, сәйкесінше Жарық нүктесінің параметрлері өзгеретіні, деректерді

өңдегеннен кейін аппараттық-бағдарламалық кешен орын ауыстырудың сандық мәнін беретіні анықталды.

Түйін сөздер: карьер, орын ауыстыру, тау жынысы, аспаптық массив, аппараттық-бағдарламалық кешен, талшықты-оптикалық сенсор, геотехникалық күй

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АППАРАТНО-ПРОГРАММНЫЙ КОМПЛЕКС ИДЕНТИФИКАЦИИ СМЕЩЕНИЯ ГОРНЫХ ПОРОД КАРЬЕРОВ

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Аннотация. Данная статья посвящена вопросу разработки аппаратно-программного комплекса идентификации смещения горных пород карьеров, который позволяет измерять несколько параметров непрерывно и своевременно уведомлять персонал горных предприятий, осуществляющих разработку подземным и наземным способами. Программное обеспечение, входящее в состав аппаратно-программного комплекса, является простым в использовании и позволяет вносить изменения в информационный интерфейс. Аппаратно-программный комплекс осуществляет сбор, обработку и анализ данных с волоконно-оптических датчиков, которые контролируют геотехническое состояние прибортового массива. Аппаратно-программный комплекс подключается к волоконно-оптическим датчикам, при помощи оптических проводников, тем самым исключается использование дорогостоящего медного кабеля. Волоконно-оптические датчики являются искробезопасными и взрывобезопасными, а также имеют высокую устойчивость к электромагнитным помехам. Аппаратно-программный комплекс с волоконно-оптическими датчиками позволяет реализовать мониторинга геотехнического состояния горных выработок карьеров. Принцип работы аппаратно-программного комплекса основан на сравнения апертур и интенсивности световых пятен при помощи фотоприемника высокого разрешения. Установлено, что дифракционные пятна и их пиксельная картина не меняется при отсутствии смещения горных пород прибортового массива, при возникновении смещения световая волна проходящая через волоконно-оптическим датчикам изменяет свои свойства, соответственно меняются параметры светового пятна, после обработки данных аппаратно-программный комплекс выдает численное значение смещения.

Ключевые слова: карьер, смещение, горная порода, прибортовой массив, аппаратно-программный комплекс, волоконно-оптический датчик, геотехническое состояние

Introduction

At present, in Kazakhstan, a large share of the mined minerals belongs to open-cast mining. The open pits showed higher technical and economic indicators compared to mines. One of the positions to ensure the minimum operating costs of mining is to achieve the maximum slope angle, as this will ensure the minimum amount of overburden. When the maximum slope angle is reached, there arises the problem of the sides and ledges stability. To ensure the safety requirements for mining operations, it is necessary to monitor constantly the geotechnical state of the mine working. The main aspect of the work of any mining enterprise is the work safety, for which it is necessary to have reliable information of the geotechnical state of the mine working, and in the event of displacements, the personnel must be notified and appropriate measures must be taken. Therefore, collecting the necessary information and timely transferring it to the decision maker is one of the important problems that require attention.

The hardware-software complex (HSC) and fiber optic sensors (FOSs) are able to measure the following parameters with high accuracy: rock displacements, air temperatures, the stress-strain state of mine workings, gas contamination. Unlike traditional electronic sensors, fiber optic sensors cannot create situations that lead to an explosion or fire in a mine working, because they are not sensitive to voltage drops and cannot create a short circuit. The use of HSC and FOSs will permit the mining enterprise to move to implementing digitalization and to transfer to a new level of using digital optoelectronic technologies. Earlier articles (Alkina et al., 2022: 1; Mekhtiyev et al., 2023: 2) have already described in detail the problems of controlling stability of the pit sides and slopes, the control methods used, and considered the FOS design, published the results of studying and testing displacement sensors. In these publications, there is presented justification for the use of FOS. This article is a logical continuation of the previously published results of the FOS study (Mekhtiyev et al., 2023: 2; Neshina et al., 2023: 3) and only HSC is considered in detail.

The purpose of this work is to develop a hardware-software complex for identifying the displacement of pit rocks to improve the mining operations safety and digitalization of control and measurement processes in mining minerals. The object of the study is a hardware-software complex designed to change the parameters of the geotechnical state of a mine working and to warn the personnel about a sudden collapse of slopes.

Relevance and problem definition

The first step in the development of a hardware-software complex for identifying the displacement of pit rocks, which is part of a new generation security system with high technical characteristics and measurement speed, capable of operating in explosive environments of mining enterprises based on optical sensors, is to carry out an analytical study of the available results in this area based on systemic approach and problem solving.

Fiber optic technology has been introduced into the mining industry for strain detection since 2006 (Nizametdinov et al., 2015: 4). The world manufacturers of FOSs are the Siemens, the ABB, the Roctest, the Weterford, the BackerHughes, the Halliburton, the Schlumberger companies and the Russian enterprises: Omega, Optolink, Intel Systems.

The development of a safety system based on the use of optical fiber will make it possible to abandon the use of equipment that measures technological parameters and make the transition to the use of fiber-optic sensors. One solution to this problem is the use of fiber optic sensors and technologies.

There is information of developing a system of monitoring rock displacement and preventing the collapse of mine workings in coal mines in China (Liu et al., 2018: 5; Su et al., 2016: 6). There are considered fiber-optic vertical and horizontal seismic receivers based on the Mach-Zehnder interferometer, where the authors propose an original design of a sensitive element that provides a high threshold sensitivity of the measuring device to seismic accelerations (Shadab et al., 2022: 7; Kamenev et al., 2014: 8). Stability of the Mach-Zehnder interferometer is ensured by the use of active stabilization of the operating point (Kim et al., 2015: 9). In the work by (Lanciano et al., 2020: 10) it was possible to solve partially the important problem of reducing the fading of the strainmeter output signal with changing the external temperature. Although the use of a multi-turn sensing element (Fursa T.V. et al., 2019:11) in the design of FOS can significantly improve the performance of FOS in strain measurements (Yiming et al., 2016: 12), but they did not manage to get rid completely of the negative effect of temperature (effects of thermal elasticity) on the measurement process.

The problem of a sudden collapse of a mine working leads to economic losses and downtime of the enterprise, and provides a significant danger for the working personnel. Analyzing some works (Fan et al., 2019: 13; Wu et al., 2011: 14; Rovera et al., 2023: 15) showed that that problem was quite acute and had been partially solved. At the moment, there are no own developments in Kazakhstan that are introduced into production and are capable of controlling the geotechnical state of mine workings of a considerable length. In the works of foreign authors, there is information of the rock massif stability to ensure safety and long-term planning of mining operations in relation to the development and distribution of fiber-optic technology for monitoring the structural state (Heo et al., 2019: 16; Yerzhan et al., 2023: 17; Wu et al., 2011: 18).

Developing a hardware-software complex

The idea of developing a hardware-software complex for identifying the displacement of pit rocks using fiber-optic sensors consists in using a telecommunication single-mode optical fiber as a sensitive element and a sensor in the control system. The optical fiber takes on a mechanical action that causes changing the properties of the mode light (phase, frequency, intensity) passing through its core. All the changes are recorded on the photodetector of the signal processing and decision-making device installed at the output of the optical fiber. Based on the studies, a version of an intelligent hardware-software complex has been developed that allows estimating the level of additional losses that occur in the optical fiber cladding with subsequent conversion into a numerical value of the measured parameters in real time. Four FOSs are connected to the hardware-software complex (HSC) to control the displacement of rocks in the area where it is necessary to carry out observations. Figure 1 shows the window of the developed HSC that is able to work simultaneously with four FOSs and to control the displacement of rocks in four sites.

1 - "start in background" button; 2 - "stop" button; 3 - block "settings"; 4 - block of "devices for displaying measured values"; 5 - block "signaling and sending messages".
Fig. 1 - Window of the developed HSC

Laboratory and field tests of the HSC and FOS have shown their performance and ability to adequately respond to the displacement of rocks. The HSC is capable of measuring displacements with sufficiently high accuracy and linearity using FOS. The research results have already been published previously (Alkina et al., 2022: 1). The design and the principle of the FOS operation has already been discussed in detail earlier (Mekhtiyev et al., 2023: 2; Neshina et al., 2023: 3), the information of the operation of the HSC is also given there. The FOS responded quite well to changes in soil displacement parameters.

For the user, the interface is not difficult, since the HSC operates in a continuous automatic mode and the operator does not need to configure it but only to monitor the instrument readings. Since a person is involved in the control, not only numerical indicators are displayed on the computer screen but also tracks of bars are presented, which perform the function of visualizing changes in the parameters. Each measurement channel has alarm indicators that are triggered by a sudden change in the offset parameters of any channel. If the offsets increase only slightly, the green indicator lights up. If changes have occurred and the offsets are growing fast enough, the red indicator turns on. The yellow indicator lights up in the event of a slight increase in displacements and is necessary to attract the operator's attention. The yellow indicator can light up during seismic activity, an industrial explosion, the passage of heavy equipment near the FOS, vibration from drilling equipment or other impact on the FOS, but this is only a warning to attract the operator's attention.

Starting the HSC operation is carried out by pressing the "start in background" button, position 1, while the green indicator lights up and the real-time control process begins. To disable the HSC and to disable it for setting, use the "stop" button, position 2. After making changes to the setting, be sure to click the "apply" button. The "settings" module, position 3, allows working with four FOSs, setting each in turn by pressing the "camera" button. Each channel can be configured individually, for this there are four buttons "camera 1-4" (Figure 2).

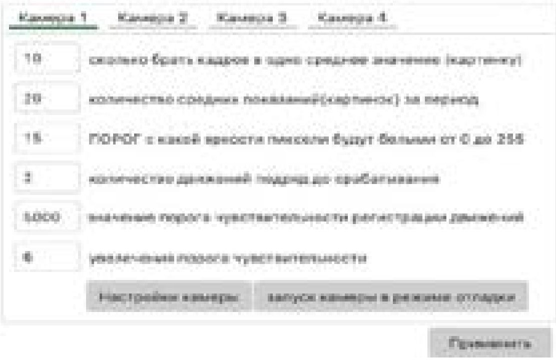


Fig. 2 – The camera setting block

The first line "How many frames to take in one average value" serves to set a numerical value for the number of frames recorded by the photomatrix per unit of time. The HSC performs averaging the number of frames and forms one image, this is necessary to reduce noise. On average, the photomatrix reads 30 frames per second, averaging 10 frames every 0.33 seconds. The HSC can be configured to average readings over a period of time using the line "number of average readings over a period of time". These parameters directly affect the detection sensitivity and the HSC response time. The next line is the threshold constraint "Threshold with which brightness the pixels will be white from 0 to 255". This parameter expresses the color value of a pixel in grayscale (from 0 to 255), at which a response will occur when a pixel changes from black to white, this is necessary to calculate changes in the pixel pattern of the light spot and issue numerical values of the measured value. This setting directly affects the detection sensitivity of the HSC. Next there comes the setting of the lines “sensitivity threshold value”. This is the setting of the numerical value of the motion detection threshold and the analysis of the number of white pixels; when the setting is exceeded, the red indicator lights up. The last line of the setting is "increasing the sensitivity threshold". Here the value of increasing the sensitivity threshold by N is set, when registering changes in parameters within a certain period of time.

Block 4 contains digital displays for displaying the measured values. Each channel has a separate display. The signaling and message sending module, position 5, is separately highlighted. The notification is sent through the Telegram cross-platform instant messaging system (messenger).

The HSC has the ability to register the received data with time logging. It records all the readings for the current run, all the values are stored in the computer's memory (Figure 3).

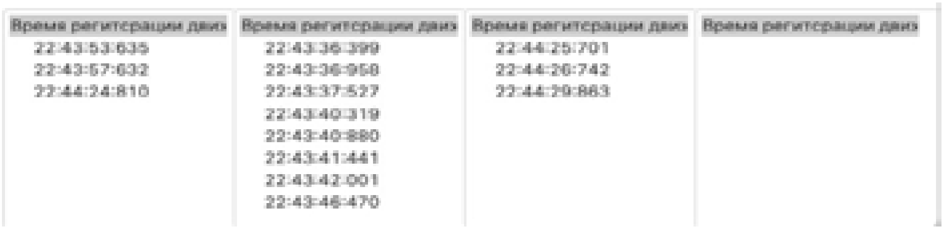
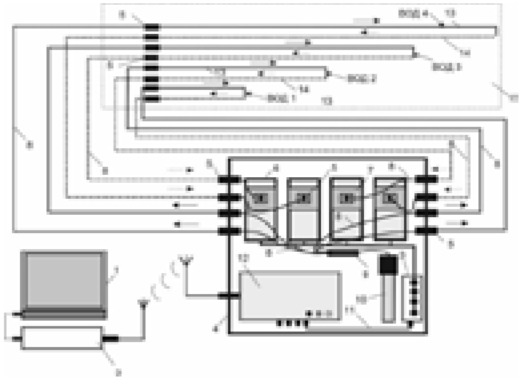


Fig. 3 – Block of registering the motion with entering logs over time

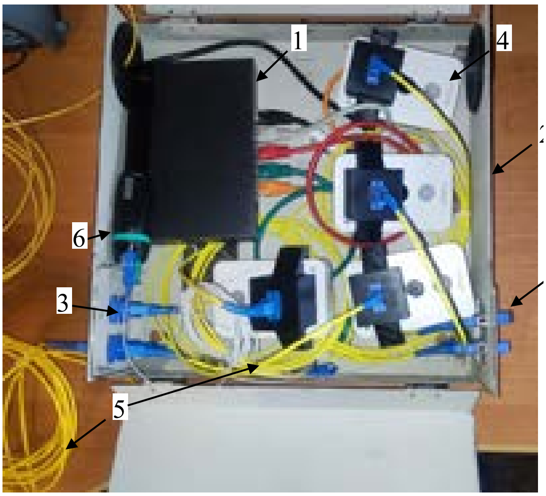
The HSC layout with the connection of the FOSs is shown in Figure 4. To control the displacement of rocks, it is necessary to install the FOSs and to connect them to the data processing unit, which, in turn, communicates with a personal computer or server via a radio channel. The hardware part is located in the housing of data processing unit 4, where there are four optical modules 6, radiation source 10 and communication module 12. Optical modules 6 are connected to Ethernet switch 3 using connecting wires. Each optical module contains a photomatrix and a microprocessor from IP cameras, which are located in a single housing. Each measuring channel with FOS is connected to its own optical module. Ethernet switch 3 is connected to the communication module with the help of Ethernet cable 11, through which information is transmitted to a personal computer via cellular communication channels. The optical modules 6 are powered from the Ethernet switch. Each optical module is equipped with an optical adapter 5, type SC and a square optical waveguide 7. Optical ¼ splitter with SC type connectors, position 9, divides the light wave from radiation source 10 into four equal parts. For switching FOS, radiation source and optical modules, optical patch cord 8 with SC type connectors is used. Patented optical patch cords with convectors and adapters provide a detachable connection, which is extremely important for field installation. The HSC can simultaneously work with four FOSs 1-4. The light wave from the radiation source passes through the optical splitter, optical patch cord and reaches the FOS, this straight direction 13 is shown by a solid arrow and a line. After passing through it, the light wave returns in the opposite direction 14, which is shown by a dotted arrow and a line back to the data processing unit, namely to the optical module.



1 - personal computer with software; 2 - communication and coordination module with a personal computer; 3 – Ethernet switch; 4 - housing of the data processing unit; 5 – optical adapter of the SC type; 6 - photomatrices and microprocessors from IP cameras in a single housing (optical module), 7 - square housing of the optical module (optical waveguide); 8 – optical patch cord with SC type connectors; 9 – optical splitter ¼ with SC type connectors; 10 – radiation source; 11 – Ethernet cable; 12 - communication module; 13 - straight direction of the FOS; 14 - opposite direction of the FOS; 15 - section of the FOS installation.

Fig. 4 - Scheme of the HSC layout with the FOS connection

Fig. 5 shows a prototype of the HSC.

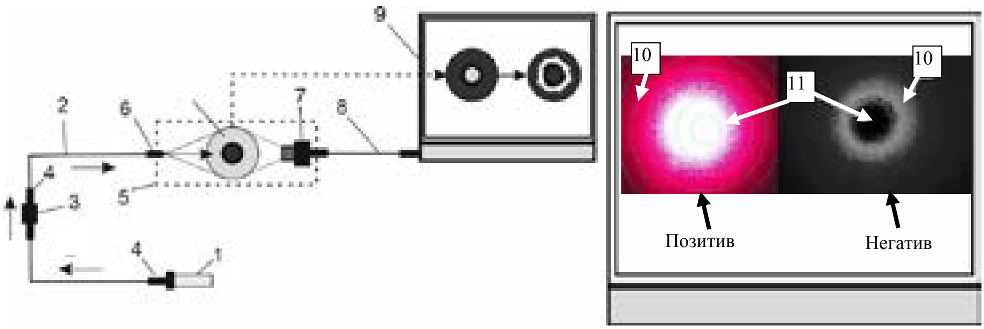


1 – Ethernet switch with communication module; 2 - housing of the data processing unit; 3 – optical adapter of the SC type; 4 - photomatrices and microprocessors from IP cameras in a single housing (optical module), 5 - optical patch cord with SC type connectors; 6 – radiation source.

Fig. 5 – The HSC prototype

Results and discussion

When the button "start the camera in mode" is pressed, a window appears with the image of a light spot and graphs. The work of the HSC is based on the method of controlling the intensity and additional losses using an intelligent electronic optical analysis of a light spot incident on the surface of a high-resolution photomatrix installed at the output of the FOS. Figure 6 presents an explanatory diagram, which reveals the essence of the method. The HSC processes the data associated with changes in the properties of the light wave passing through the FOS. As mentioned earlier (Mekhtiyev et al., 2023: 2; Neshina et al., 2023: 3), when mixed, the ends of the optical fiber diverge from each other, additional optical losses increase. The HSC evaluates the changes and gives the numerical value of the measured displacement value. In this case, changes occur in the pixel pattern of the light spot, since transition of pixels from a valuable color to white pixels begins. The method is based on comparing changes in the parameters of the light spot over time and the process of transition of pixels from one state to another. The greater the displacement, and hence the divergence of the ends of the optical fiber, the higher the level of additional losses, therefore, the lower part of energy of the light wave comes to the photomatrix, so, the spot becomes less intense. The value of the formed additional optical losses during the divergence of the OF is directly proportional to the number of formed white pixels. The shift causes changing the numerical pattern of the pixels and their transition from black to white.



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1 – radiation source with the wavelength of 650 nm; 2 – optical patch cord; 3 - FOS; 4 – optical connector; 5 – optical module; 6 – input device (optical waveguide); 7 – photodetector with microprocessor; 8 – USB cable; 9 - personal computer with software; 10 - light wave propagating through the core; 11 - light wave propagating along the shell.

Fig. 6 - Explanatory diagram

The light spot incident on the sensitive surface of the photomatrix has a positive image, a bright core and a less bright shell, there is an interface between them. The light spot resembles a Poisson spot, has the stepped Gaussian distribution profile, since a single-mode OF is used. The light wavelength used is 650 nm. Its movement from the radiation source to the FOS and the photomatrix is shown by arrows. The positive image of the light spot is converted into the negative one by the program.

Since the core is too bright and not informative, and contains a sufficiently significant noise level, it is excluded from the intelligent optoelectronic analysis using the Python program. Figure 7 shows a numerical picture of the growth of white pixels, when the ends of the optical fiber diverge inside the optical ferrule of the FOS.

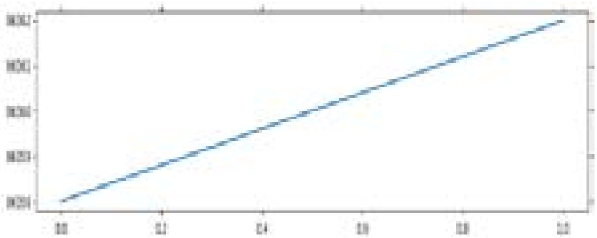
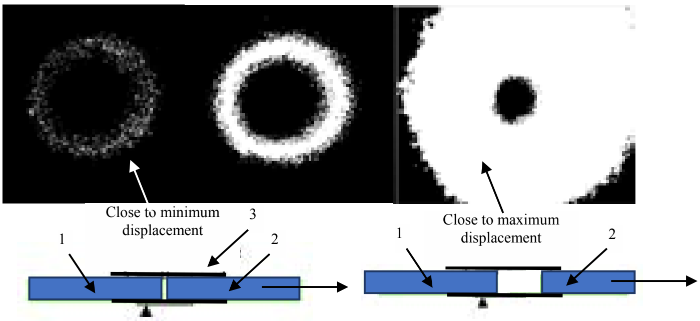


Fig. 7 – Numerical picture of the white pixels

The PC has built a graph that shows that the number of white pixels increases from 86358 units to 86362 in 1 second when the ends of the fiber are shifted. In the experiments, photomatrices with a lower resolution of the VGA format, 640x480, has proved to be quite good, which gives a total of 307200 pixels that is enough to control the displacement from 0 to 150 mm. When using a photo sensor with resolution of, for example, 720p (HD), this is 1280 columns and 720 rows of pixels, which gives a total of 921,600 pixels; the displacement can be controlled up to about 300 mm. The experiments and field tests of the HSC show that with increasing the gap between the ends of the OF, in the situation of the code, the FOS detects the rock displacement, additional optical losses grow in proportion to the size of the gap, while the number of white pixels also increases in proportion to the distance between the ends of the OF.



1 - fixed end of OF; 2 - fixed end of OF; 3 - optical ferrule

Fig. 8 - Increasing the number of white pixels when the ends of the fiber diverge

This makes it possible to build a sufficiently accurate FOS with a high linear characteristic to measure the displacement parameters depending on the change in the properties of the light wave passing through the fiber core when their ends diverge inside the optical ferrule.

Such complexes can be used wherever it is necessary to provide communication between devices without using an expensive cable, which is also intrinsically safe. It is very convenient to use this complex to connect security sensors and actuators with a control computer.

Conclusions

The hardware-software complex for identifying the displacement of pit rocks of the developed system is able to evaluate changing the intensity of the light spot at the exit from the fiber using artificial intelligence algorithms. The proposed method of identifying the geotechnical state of mine workings is implemented by comparing the apertures of light spots. The advantages of the hardware-software complex include the ability to develop the configuration and to make changes online, the ability to change failed equipment without turning off the power.

The developed hardware-software complex is designed for operational control of sudden changes in the parameters that affect the pit walls strength with the prospect of multi-measurements. The developed software provides multi-channel processing of the data received from fiber-optic sensors.

The system can also change step-by-step its sensitivity. It is initially 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 fix accurately the displacement and to eliminate false measurements. The fiber optic sensor used has a fairly linear characteristic and is highly sensitive to any change in the displacement parameters when the pressure on the sensor changes.

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