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The use of optical fiber to control the sudden arch collapse of the mine working

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Abstract. The relevance of the work is due to the importance of creation of information-measuring systems and monitoring systems of a new generation to ensure the safety of mining operations and coal production which allow to control all the necessary parameters. The aim of this work is the development of information-measuring system for monitoring the technical condition of the mining facilities.

1. Introduction

The high-level mine safety requirements create the certain difficulties for the manufacturers of mining equipment forcing them to raise its production cost as compared with the general industrial equipment. The important circumstances are the control of state of mine workings and the mine atmosphere as well as the technical and technological status of equipment in the underground mining workings.

The use of optical technologies will allow to put into practice the intrasite fiber-optic information-measuring systems (IMS) for the measurements of parameters and physical quantities and the diagnostics of the technical condition of mining machinery and equipment. The system data for the mining industry of the mines of Karaganda coal basin is particularly relevant and can obtain a number of significant advantages as compared to the traditional electronic measuring systems especially under the conditions of increased spark- and explosion hazards at production sites which are hazardous in explosion of gas and dust.

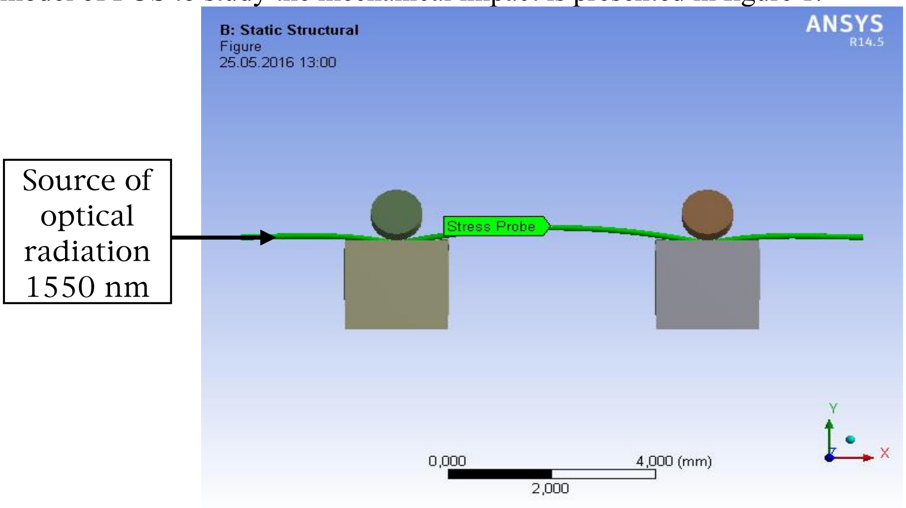
Our work is focused on creating of high-quality IMSs based on the fiber-optic sensors (FOSs) with improved metrological and operational characteristics by using the achievements of foreign scientists that will allow solving a number of safety issues when operating in difficult and dangerous conditions of the coal industry [1].

2. Research method

Building on the achievements of foreign scientists and taking into account the well-known advantages of the fiber-optic sensors (FOS), we work to create the high performance information and measurement system (IMS) based on the fiber-optic sensors with improved metrological and operational characteristics for subsequent implementation in the mining sector of Kazakhstan which has enabled a number of security issues to be solve when operating in difficult and dangerous conditions of coal mines of Karaganda coal basin [2].

To create the IMS based on the FOS the research was conducted which is aimed at finding a structural design of the pressure control sensor of the rock mass on the timber elements. It was determined the impact from the rock mass which can create the danger of the sudden collapse of the arch, as well as set the movement, deformation and destruction of rocks. The work of sensors is aimed to measuring in the zone of bearing pressure as at the opening of rock mass the pressure coming on the walls of working is much higher than in the intact rock mass because the balance of the stresses is disturbed. The change in the nature of the stresses is shown as follows: the regions are formed with a low value of mechanical stresses in the roof and soil of mine working and increased in the side walls while the tensile stresses are dominated in the roof.

The model of FOS to study the mechanical impact is presented in figure 1.



1 – Optical fiber, 2 - steel rods with a diameter of 1 mm, 3 - elastic rubber pad

Figure 1. Model of FOS to study the mechanical impact.

Around the contour of mine working the natural cracks are formed, the excess energy high concentration of which leads to destruction of the contour and the formation of open cracks.

To simulate the process of the impact of rock pressure on the timber elements and the definition of the parameters of this impact the program was used based on ANSYS STATIC STRUCTURAL finite element method. The object of the study was the fiber-optic sensor developed by us for the measurement of overburden rock pressure on the structural elements of the timber.

3. Equipment and methods of research

As a measuring element we use an optical fiber with diameter 9 microns, located on two dampers that represent two rubber pads. The confining pressure is transferred to two steel rods located at a distance of 4 mm from each other. Further, the number of contact points will be increased to several tens as two points is obviously not enough to control the pressure of massif's rocks. It will also be possible to change the distance between the rubber pads. The source of optical radiation is taken with a wave length of test range of 1310nm, 1550nm, 1625nm. To simulate the pressure on the steel rods and the transmission of it to the optical fiber it is used the capabilities of ANSYS software product with the help of which the experiment was conducted. ANSYS allows calculating the displacements, strains, stresses, internal forces arising in the body under the action of static load. The parameters of the finite element model and the physical-technical data are specified in the Mechanical application. We have assigned the necessary physical parameters to the elements of the model in accordance with the conditions of the experiment. We used the basic properties of contact interactions of elements in the calculation. The result of the calculation was the calculation of mechanical stress in the contact area of the optical fiber of the steel rod. In addition, the visualization of pattern of the mechanical stresses and strains distribution was obtained with precise imagery of the stress distribution at each point of the computer model.

The processing of experiments results was conducted with Wolframalpha computer program, and the appraisal of the results is evaluated according to selected criteria:

AIC - Akaike information criterion;

BIC – Bayesian information criterion;

R2 - determination coefficient;

Adjusted R2 - Adjusted R2.

Numerical study of FOS model of mechanical stresses and strain are carried out using Wolframalpha program, which is an interactive system for processing of experimental results and oriented to work with data arrays. Wolframalpha is developed by the famous mathematician Stephen Wolfram based on the theory of computability and it is a system of computer algebra, as well as a knowledge base and a set of computational algorithms based on the first one. [3]

Boundary condition: the pressure on the steel rods from 1 to 10 MPa, the increment interval of 1 second, the pressure changes to 1 MPa, the initial pressure conditions Q=0 MPa, 10 increments in total, the temperature is 23°C in the laboratory room. The axes movement after the application of pressure is OX=0 m; OY=0 m; OZ=0 m. One-factor mathematical models were received at the result of the automated approximation of the obtained experiment data through Wolframalpha program.

A graph of variance of the strain value of the optical fiber with step-by-step increase of pressure on the metal rods is presented in figure 2.

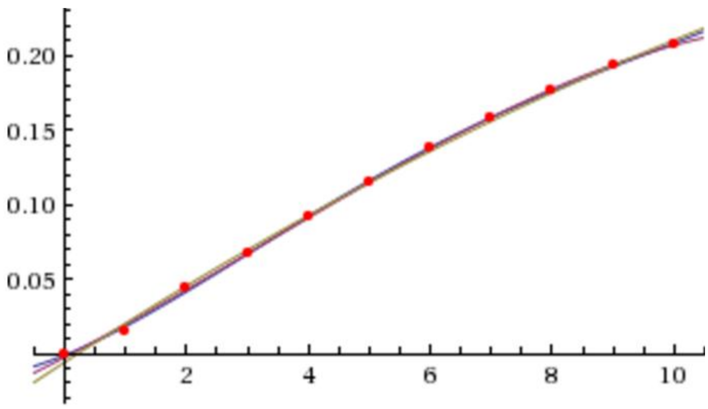


Figure 2. The strain value ε of the optical fiber with step-by-step increase of pressure on metal rods.

The dependence of the strain values ε is represented by a mathematical model with various types of approximation:

1. 1. $\varepsilon=0{,}000018951Q^4 - 0{,}000472288\,Q^3+0{,}0032662\,Q^2 + 0{,}0165598\,Q - 0{,}00127462$ (quartic approximation);
2. $\varepsilon=-0{,}0000932673\,Q^3 + 0{,}000897319\,Q^2 + 0{,}0212976\,Q - 0{,}00263909$ (cubic approximation);
3. $\varepsilon=-0{,}00050169\,Q^2 + 0{,}0266324\,Q - 0{,}00599671$ (quadratic approximation).

The values of criteria when conducting the approximation are presented in table 1.

Table 1. The approximation results.

Approximation	AIC	BIC	R2	Adjusted R2
quartic	–100,704	–98,3164	0,999263	0,999263
cubic	–97,2166	–95,2271	0,998959	0,998959
quadratic	–89,4635	–87,872	0,998232	0,99779

In calculation we used the basic properties of contact interactions of elements. The result of the calculation was the estimation of mechanical stresses in the contact area of the optical fiber and the steel rod. In addition, it was obtained the process visualization of mechanical stresses and deformations with accurate representation of stress distribution at each point of the computer model.

Yokogawa AQ1200E is a multifunctional tester because in addition to the functions of reflectometer it can be equipped with individual port of the power meter to measure the losses, a source of visible radiation to find the damages, a video feeler to check the optical connectors. We carried out the experiments with G-652 single-mode fiber with a length of 7.5 meters, 10 experiments were conducted with different number of bends of the optical fiber. The optical fiber is intended to transfer information at large distances and a large number of channels. It should have the low attenuation and dispersion and the large information-carrying capacity. The single-mode fiber with the size of the core and shell of 8/125 microns is used. The source of optical radiation is taken with wave length of test range of 1310nm, 1550nm, 1625 nm [4, 5]. The experiments were conducted with FOS on the basis of scattering effects. The Brillouin scattering occurs due to the presence in the fiber optic of acoustic waves excited by thermal oscillations in the GHz range. Scattering can be presented as a diffraction of light on a dynamic grating induced by acoustic waves. The diffracted radiation has also the Doppler Effect as the acoustic wave is spread along the fiber with a finite rate, and this rate depends on the density of the medium, which in turn is determined by its temperature and internal stress. Thus, the detection of signal of Brillouin scattering gives information about the temperature distribution and strain along the optical fiber.

4. Conclusions

The studies have shown that the simulated FOS has a slight nonlinearity with applied pressure on the steel rods from 1 to 10 MPa respectively there may be used as the measuring body from the side of the rock mass to control the sudden collapse of the arch of mine working.

According to the results of the experiment the experimental graphs were built showing the relationship between the magnitude of the applied pressure and the difference in the readings of the reflection meter.

It should be noted that with further increase of the load on the fiber, the difference in the luminescence of signal is not already registered by the device, because the signal level back from the point of application of pressure becomes too low. However, the dependence between the increase of back reflection of the signal caused by the strong bending of the fiber and the pressure goes to the linear section. Thus, the sensor has the ability to register a higher pressure without undergoing any additional configuration changes.

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