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Determination of stress-strain state of a rock mass on the basis of soundmetric control methods

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The article defines the main approach to the selection of seismic sensors to obtain the necessary signal that will determine the stress-strain state of the mountain massif. A schematic diagram of equipment for recording and collecting audiometric information has been developed. An approach to signal processing has been developed and primary research on the identification of phenomena has been performed. A number of phenomena that are characteristic of any career are identified and their soundmetric data are determined. Scientific novelty:For the first time, a method was proposed to take into account the degree of disturbance of the board by underground mining through soundmetric observations with subsequent separation of phenomena and selection of the intensity of destruction of the rock mass. Initial conclusions were made regarding the possibility of identifying phenomena and determining the direction where this phenomenon occurred.

Keywords: soundmetry, pit, geotechnical events, cracks

Визначення напружено-деформованого стану масиву гірських порід на основі звукометричних методів контролю

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У статті визначено основний підхід до вибору сейсмодатчиків для отримання необхідного сигналу, який забезпечить визначення напружено-деформованого стану гірського масиву. Мета статті: розробка алгоритму визначення мікросейсмічної активності масиву гірських порід, який порушений шахтними виробками, та розробити принципову схему обладнання, яке допоможе фіксувати та збирати звукометричні дані. Окрім зазначеної мети в статті приведено розроблений підхід до обробки сигналу та виконання первинних досліджень по ідентифікації явищ. Виділено ряд явищ, які є характерними для будь якого кар'єру та визначені їх звукометричні дані. Проведені дослідження охоплюють дослідження з денної поверхні, дослідження над устям свердловини та дослідження безпосередньо у свердловині. Приводиться опис основних результатів дослідження та порівняння між собою отриманих значень інтенсивності виникнення зафіксованих явищ. Розглянуто переваги та недоліки безперервного моніторингу масиву гірських порід в межах кар'єрного поля. Наукова новизна: вперше запропоновано спосіб врахування ступеню порушеності борту підземними гірничими роботами через проведення звукометричних спостережень з подальшим відокремленням явищ та виділенні інтенсивності руйнування масиву гірських порід. Зроблені первинні висновки щодо можливості ідентифікації явищ та визначення напрямку, де це явище відбулось. Наводяться висновки відносно чутливості вимірювальних каналів, яка достатня і обмежена на поверхні впливом вітру і шумів. Хоча проведені дослідження допомогли розділити більшість явищ і визначити їхні характеристики, але ряд реакцій на даному етапі не розділені достатньо впевнено на природні, чи техногенні. На розробку правил ідентифікації таких сигналів недостатньо експериментального матеріалу, тому в подальшому планується проводити додаткові серії досліджень, щоб отримати максимально впевнений набор статистичних даних для класифікації явищ.

Ключові слова: звукометрія, кар'єр, геотехнічне явище, тріщинуватість

Introduction

For the Kryvbas region, one of the problems is the control of the behavior of voids and rock mass, in which there are spent mine processes. A complex of gravimetric, soundmetric, surveying, electrometric and other methods of observation is used to ensure safety during mining operations in quarries located in the area of influence of mine cavities (voids). This set of methods allows to monitor the processes of change of the stress-strain state of the rock mass.

Previously, most high-precision observations are performed using computer processing of information and recording of signals in electronic form. The sound method of monitoring the stress-strain state of the rock massif currently relies only on the sound sensations of the operator, who listens through headphones to the number of events and tries to estimate their intensity, and the nature of these events, the operator cannot identify [1, 2].

Review of the research sources and publications

The State Research Mining Institute (SRMI) has performed report [9], which provides an assessment of the state of the spent space and the possibility of funnels on the worked areas of the earth's surface. A map of the actual state of voids and danger zones on the eastern side of the quarry №1 PJSC "Central GOK" was compiled. The map is based on generalized data of calculations according to the current "fork of labor protection during open pit mining" [10] and the results of interpretation of geophysical surveys by RAP (radio-acoustic polarization) and PNEMFE (pulsed natural electromagnetic field of the Earth). The map includes a combined plan of voids obtained on the basis of geological and surveying documentation on previously worked cavities, the actual location of mining operations and anomalous zones, selected according to the results of the analysis of the development of landslide and observation processes by RAP and PNEMFE methods and other geophysical methods in the area of underground works by mines that named: «Frunze», «Bolshevik» and «Oktyabrskaya». In the research and development of the calculation and empirical method performed the assessment of the funnels possibility. For a selected area, the safety of mining at a design depth of 500 m Gleyevat quarry is justified. Mining in this area is possible without prior repayment of voids. Instead, areas where quarrying without prior void closure is dangerous have been identified. The data given in the Research work [9] are consistent with the data of enterprise state institute on designing the enterprises of ore-mining industry KRIVBASSPROEKT (SE SPIKRIVBASSPROEKT) [11].

In the stress state of the rock or when increasing the force on the formation due to the formation of a void space under the ground at some point in time, a stress equal to the flexibility limit is achieved. At this time there is event of avalanche-like formation of microcracks, which is called the effect of acoustic emission due to the accompaniment of residual deformation by radiation of elastic waves of the sound frequency range. The frequency spectrum can be used to qualitatively judge the size of cracks, the level of force stress on the local block of rocks and in general the stage of stress state of the array or part thereof [3-4].

Selection of previously unsolved parts of the overall problem. One of the most important tasks in conducting mining operations in such conditions is to ensure the safety of all terrestrial and underground facilities, which are located near the zones of mass disturbance of the natural geomechanical state of the rock mass [5-6]. One of the features of the behavior of man-made voids is the uncontrollable, relatively slow, "emergence" of voids and the rapid development of the process when it reaches a critical value. Depending on the specific physical and mechanical properties of rocks, depth of development and volume of work, deformations may reach the earth's surface, and may not reach the surface at all. In the first case on a surface zones of shifts, cracks and terraces, collapses are formed. This leads to the destruction of all objects of natural and man-made origin, which are located above the voids. In the second case, the zone of destruction of the rock mass is localized in the subsoil [7-8].

The purpose of the article is to create an algorithm for determining the microseismic activity of the rock mass, which is disturbed by mine processes, and to create a schematic diagram of equipment that will help capture and collect sound data.

Basic material and results

To measure the background sound parameters in wells and on bare rock mass with the help of ADC (analog to-digital converter) and bicycle meters, first of all it is necessary to determine the required sensitivity of sensors (Table 1).

The measured values for the assessment and separation of event are selected: the speed of the geomechanical phenomenon of oscillations of the array, meters per second and the acceleration of oscillations of meters per second squared.

Based on the initial data and research objectives, which are to record and separate a number of sound event, which will investigate the stress-strain state of the rock massif, a simplified diagram of the basic equipment needed for research.

Equipment connection diagram (Fig. 1). From the probe, the signal enters the ADC, where it is converted nto a digital signal and transmitted to a laptop. The ADC is connected to a 12V power supply (battery), the required voltage is supplied to the laptop via the power supply (inventory). After the signal is converted, it is recorded on a laptop or connected flash card, but a laptop or computer is still required to process the recorded information.

The design of the probe can consist of three magnetic-dynamic bicycle meters or three piezoelectric seismic sensors with built-in signal amplifiers with current modulation of the output signal. The ADC unit also includes an adjustable amplifier, a direct analog-to-digital converter and a controller with signal transmission indicators.

Table 1 – Sensitivity selection and calculation of the transmission factor of measuring channels with 16 and 24bit ADCs

Measured values			Recommended values			
Phenomenon	Speed, m/s	Voltage on the sensor without amplifier, μV	Share of maximum voltage, %	The output of the unit from the 16-bit ADC, units	Kki, ed.atsp • s/m	Ex. from 24-bit ADC, from
Microseismic at a depth of 1000 m	0.095•10^{-6}	3.04	0.075	24	252•10^{6}	6 144
Microseisms on the surface	0.127•10^{-6}	4,064	0.10	32	252•10^{6}	8 192
Microseismic in the city	0.381•10^{-6}	12,192	0.30	98	257•10^{6}	25 008
Cracks	0.32•10^{-6}	10.24	0.252	82	257•10^{6}	20 997
Macrocracks	1,588•10^{-6}	50,816	1.25	409	258•10^{6}	104 704
Shocks	6,350•10^{-6}	203	5.00	1638	258•10^{6}	419 328
Maximum registered local earthquake	31.96•10^{-6}	1.0227	25.00	8192	256•10^{6}	2 097 152
			100	+\- 32 768		+\- 8 388 608

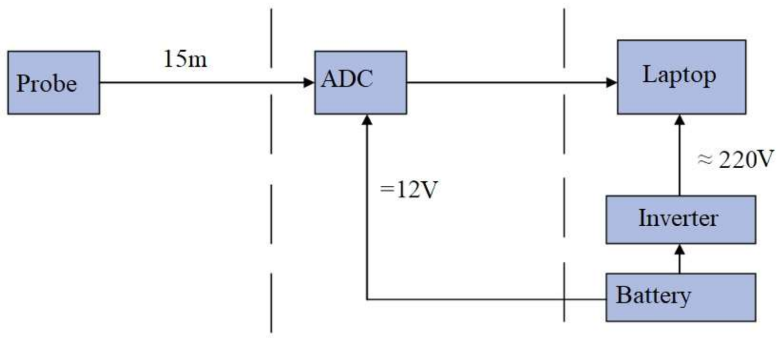

Figure 1 – Equipment connection diagram

Table 2 – Event sound characteristics record form

№	Acceleration, silence mode		Acceleration max,		Mt, ms\cl scanning	T, ms	Tn	Ts	F, Hz	Notes
	Cells	m/s^2	Cells	m/s^2						
1.10	0.35 0.3 0.3	2.64•10^{-3} 2.26•10^{-3} 2.26•10^{-3}	2.6 3.0 2.0	19.6•10^{-3} 22.6•10^{-3} 15.8•10^{-3}	50	200 200 200	45 45 45	155 155 155	65 70 70	Impact sample 3kg
1.11	0.5 0.5 0.4	3.77•10^{-3} 3.77•10^{-3} 5.02•10^{-3}	0.8	6.03•10^{-3}	200					Traffic noise
	0.6 0.5 0.5	4.52•10^{-3} 3.77•10^{-3} 3.77•10^{-3}	1.2 0.4 1.0	9.05•10^{-3} 3.02•10^{-3} 7.54•10^{-3}	200	70 50 50	-	-	-	Kxyz =7.54•10^{-3} (m/s^2)/cl Weak phenomenon
	0.2 0.15 0.2	0.78•10^{-6} 1.47•10^{-3} 1.96•10^{-3}			200					Kx =1.0/(32·400·10·2) = 3.9•10^{-6} (m/s^2)/cl Ky =0.5 / (0.102·25·10·2) = 9.8•10^{-3} (m/s^2)/cl Kz =9.8•10^{-3} (m/s^2)/cl Noise of the loaded loco-motive on Y and Z 110Hz; 9.1Hz; 0.8Hz

Rechargeable battery with an output voltage of 12V. A program for recording, recording and signal processing is installed on the laptop.

In-house processing of monitoring results should be implemented in three stages;

– primary signal processing;

– comparative analysis of informativeness of periodic measurements and continuous monitoring of the stress state of the quarry board;

– comparative analysis of informativeness in measurements on rocks, exits of the ledges of the quarry board and in measurements from different depths of wells.

The method of signal processing should include primary amplitude normalization of signals, frequency filtering and selection, temporal selection, Fourier transform, registration and calculation of intermediate parameters, selection of significant event, identification of significant event, determination of coordinates of hypocenters of selected significant event, compilation of passports event, the distribution of event into groups depending on their characteristics.

Processing of monitoring results (arrays of event passports) includes smoothing, calculation of the average for the time interval, determination of signal distribution density, coordinates of maximum distribution density and other statistical indicators, approximation and interpretation of events according to time.

The first series of studies was conducted, which allowed to conduct the initial selection of event and record their sound characteristics in the form of (Table 2, for example), to process them and reduce to Table 3.

The overall measurement results showed the following data:

1) The sensitivity of the measuring channels is sufficient and limited on the surface by the influence of the wind, and in the well by microseisms of the Earth. Measurements on the surface were performed using sound insulation, however, there is no response even to a moderate wind. There is no reaction to a loaded diesel locomotive at a distance of 1.5-2 km. There was no need to turn on the maximum sensitivity during the measurements. According to the results of the conducted research, the numerical values of the sensitivity of the measuring channels were established.

2) When measuring from the surface, the comparison of the average values of the quiet mode and the response to shocks with the sample show a greater sensitivity when the probes are placed on a concrete surface or on the closed surface of the wellhead.

3) A comparative analysis of the informativeness of measurements from the surface, mainly from the rock outcrops of the ledges of the pit side and measurements in different parts of the wells showed:

3.1. During the period of 30 minutes of measurement from a depth of 120 m of the well, 12 significant phenomena were registered (24 per hour) with 2-3 phenomena per hour registered when measuring from the daytime surface. Thus, the frequency of registration of significant phenomena inside the well is an order of magnitude higher than from the surface.

3.2. The advantage of microseismic monitoring from wells is greater sensitivity, the absence of wind noise, rain, road traffic, and people's footsteps in the recordings.

3.3. The disadvantage of periodic microseismic monitoring from wells is the need to lower the probe 200m. About an hour of the time of two workers is needed to carefully lower the probe for 200m. It takes about half an hour to dismantle the probe and cable. Careful lowering means the exclusion of sharp jerks (the weight of the probe itself is 0.5 kg, the weight of the cable and cable is 15 kg), the exclusion of bending and twisting of the cable, the exclusion of friction of the cable against the sharp edges of the pipe (at least the upper end), the exclusion of jamming of the probe, since the wells are in the lower part not vertical.

4) A comparative analysis of the informativeness of periodic measurements and continuous monitoring of the stress state of the pit side showed:

4.1. Continuous monitoring definitely gives more information, but for its organization you need to spend a lot of additional resources, such as: continuous connection to the power grid, anti-vandal protection and processing of a large amount of information.

4.2. With periodic measurements, the time of a statistically significant measurement from a well = 100 phenomena•1.2/(24 phenomena/hour) = 5 hours. Time for mounting and dismounting the probe and equipment = 0.4 hours +1 hour + 0.5 hour + 0.4 hour = 2.3 hours. Total installation, measurement and dismantling 7.3 hours. Add time for delivery of equipment to the well and back. For other wells, where the frequency of occurrences is lower, the time of a statistically significant measurement will be correspondingly even longer.

5. Studies of the rate of oscillations of microseismic response of the massif to geomechanical phenomena, acceleration, simultaneous and sequential were conducted. Velocity and acceleration measurements showed greater sensitivity to weak signals of acceleration measurement channels with piezoelectric accelerometers. On the other hand, speed measurement channels with velocimeters and 16-bit ADC showed a greater dynamic range.

A comparison of the three-coordinate signal vector modules showed a greater sensitivity of the array-seismograph system in the northern part of the eastern side of the studied pit compared to the southern part

7) Analysis of the results of similar studies showed greater microseismic activity in the southern part of the eastern side of the pit compared to the northern part.

Scientific novelty: for the first time, a method was proposed to take into account the degree of disturbance of the board by underground mining through soundmetric observations with subsequent separation of event and selection of the intensity of destruction of the rock mass.

Table 3 – List and characteristics of geotechnical events to be controlled

Type of primary destruction		Forms of manifestation	Seismic energy, J.	The level of seismicity in the epicenter, score	T, sec	There are types of main waves
		Earth microseisms			Constantly	
Micro-cracks		Chips registered by the sound sensor	<1		0.01-0.07s	Pg
Cracks	On the ground floor	Dynamic stabbing	1-10	<1	0.07s - 0.15s	Pg
	In the array	Clicks, (micro-pushes)	$10\text{-}10^2$	1-2	0.15 - 0.2s	Pg, Sg
Macro-cracks	On the ground floor	Weak rock blows	$10^2\text{-}10^3$	2.5	0.2 - 0.3 s	Pg, Sg
	In the array	Micro shocks	$10^2\text{-}10^3$	3	0.2 - 0.3 s	Pg, Sg
		Medium power shocks	$10^3\text{-}10^4$	- \\ -	0.3 - 0.4s	
Macrocracks with shear	On the ground floor	Mining strikes	$10^4\text{-}10^5$	3.5 - 5	0.4 - 0.5s	Pg, Sg, Lg
	In the array	Strong shocks		- \\ -	- \\ -	- \\ -
Macrocracks with displacements and gaps	In the array	Mining and tectonic shocks	$10^5\text{-}10^6$		0.5 - 0.63s	Pg, Sg, Lg
- \\ -			$10^6\text{-}10^7$		0.63 - 0.8s	Pg, Sg, Lg
- \\ -			$10^7\text{-}10^8$		0.8 - 0.98s	Pg, Sg, Lg
- \\ -			$10^8\text{-}10^9$		0.98 - 1.3s	Pg, Sg, Lg
Gravity rupture		Crash	$10\text{-}10^4$	1-3.5	0.2-0.4s	Pg, Lg
Man-made earthquakes			$>10^9$		1-30s	Pg, Sg, Lg
Regional earthquakes					30-66р.	Pg, Sg, Lg, Pn, Sn, P, S, Lq, Lr
Earthquakes						P, PP, KP, S, SKS Lr, Lq
Electric locomotive						Pg,
Steps						-
Works near the probe						-
Explosion	Up to 2 kg				0.3-0.55s	Pg, Lg
	2-4kg				0.55-0.8s	
	4-20kg				0.8-2s	
	20-200kg				2-3s	
	200-2000kg				3-4с	
Mass explosion	<2т				15 - 80р	Lg groups

Conclusions:

1. The sensitivity of the measuring channels is sufficient and limited on the surface by wind and noise. Measurements were performed using sound insulation, however, the reaction even to moderate wind is noticeable. Perceptible response to traffic noise there was no need to turn on the maximum sensitivity during the measurements.

2. The area of measurements around the well for microcosmic activity is characterized as higher than average. During the observations from 1000 to 1330 there were 4 significant microseismic event. A number of reactions at this stage are not divided confidently enough into natural or man-made. At present, there is not enough experimental material to develop rules for the identification of such signals, so in the future it is planned to conduct additional series of studies to obtain the most reliable set of statistics for the classification of event.

3. Different values of the amplitude of oscillations in the coordinates X, Y and Z makes it possible to estimate the direction of the phenomenon relative to the probe.

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