On the possibility of creating a comprehensive system for rockburst prediction in mines and mining plants

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Abstract. An analytical overview of the current state of the technology for monitoring safety and transmitting messages through the rock using electromagnetic and seismic waves is given. The paper describes the possibility of predicting mountain impacts based on the seismolectric effect, which allows one to determine the time and place of gas accumulation. To increase the reliability of the forecast, it is advisable to create a comprehensive monitoring system that includes other modern monitoring methods.

Among the control facilities in mines, portable and stationary gas analyzers are mainly used, with the addition of an analysis of the data of geophones recording SA noise [1, 2].

However, gas analyzers give an idea of the concentration of associated gases discharged from the production by the ventilation system, and seismic monitoring is complicated by production noise and requires long-running software and algorithms for recognizing the occurrence of explosion hazard conditions. The seismic acoustic method has been used in the practice of continuous monitoring of outburst hazard since the 1980s. During this time, the method has received significant development, both in hardware and in scientific and methodological terms. Theoretical studies in this area were aimed at studying the mechanisms of excitation, propagation, registration, and analysis of SA wave fields [2]. The formation processes, at the same time, are so complex, and the recorded vibrations carry such an amount of information about the structure and physicomechanical properties of rocks that it can be said that the capabilities of the SA method are far from exhausted, including in terms of new data analysis methods, where machine learning methods are increasingly being used [3, 4]. Nevertheless, the CA method has a number of significant drawbacks. In addition to poor noise immunity from industrial noise, the weakest point is that monitoring the acoustic emission of the formation does not allow one to evaluate such a significant outburst hazard factor as gas, but is informative only on rock impact. This reduces the information content and reliability of the CA method.

The monograph [5], prepared in 2010 by Ashurkov V.A. (Novosibirsk), on a large practical material proves the mantle origin of the explosions. The process develops rather slowly, and as pressure builds up in a gas bubble, this gas reaches a wall in a rock through a crack in a rock. As shown in [6], the appearance of cracks is accompanied by sparking, so that under certain conditions, a mantle gas suitable for production explodes.

In the framework of the work, this drawback will be eliminated by introducing an additional observable parameter - the electromagnetic noise field and extracting information from its correlation with
microseismic noise. The seismoelectric (SE) method described in the article is aimed specifically at detecting the displacement of a gas methane bubble in a rock structure.

The first experimental field works on the detection of hydrocarbons by simultaneously recording the Earth’s seismic $S(t)$ and electric $E(t)$ noises in the frequency range $0.1$–$20$ Hz with the calculation of their cross-correlation functions was carried out at the Minusinsk gas condensate field [7].

The cross-correlation function was defined as:

$$R_{ES}(\tau) = \frac{1}{T} \int_{0}^{T} S(t) \cdot E(t - \tau) \cdot dt ,$$  

where $T$ – observation time, $\tau$ – time shift parameter.

Despite the introduction of modern gas control systems, including foreign ones, mine explosions occur regularly, which indicates the imperfection of the known methods for predicting accidents. Among specialists involved in this problem, there is a well-grounded view of this problem as a spontaneous event due to the release of gas from the mantle [5, 8]. In this case, the process is accompanied by deformation of the rock, the appearance of cracks through which gas exit channels are formed and expand. The appearance of cracks in crystalline rock causes the phenomenon of electrostatic discharge, which causes the explosion of the gas stream.

It is possible to predict such a phenomenon by supplementing the standard gas monitoring facilities with new sensors: in particular, strain meters that monitor the dynamics of the stress-strain state of rocks in the bottom hole region; seismoacoustic means for assessing the state of noise in a wide range of frequencies; electromagnetic sensors of radio wave impulse radiation caused by electric discharges in the presence of cracks long before the explosion, finally described in the article by the seismic-electric method.

A prerequisite for the reliable operation of the entire system for predicting accidents and its consequences is the availability of a two-way top-down and bottom-up information transmission system, with timely delivery to the mine dispatcher and personnel below.

Today, cordless personal top-down communication is carried out by an electromagnetic system developed in particular by the Radius engineering scientific and technical center (Krasnoyarsk), Siberian Federal University and a number of other enterprises of the Russian Federation. Up to now, an unresolved problem has been bottom-up communications, especially after emergency blockages that destroy cable lines. In this case, the filled-up transmitter is not able to transmit the current situation to the surface, because, due to the small space and high absorption of electromagnetic waves by the rock, it is impossible to deploy long-range radiating antennas.

In the period 2012–2016 the Military Engineering Institute of the Siberian Federal University, together with the specialists of STC “Radius”, developed and tested the seismic communication system ACC-1 with parameters that ensure the transmission of telegraph messages “from bottom to top” from a small space [9].

This system, in conjunction with new monitoring sensors, is capable of simultaneously transmitting current information about the face condition to the mine manager in parallel with cable and other means of communication. Having a reliable messaging system is only part of the solution to the security problem.

The most important complex in the security system is also the receipt of fairly reliable information from sensors for predicting rockburst. The following describes the possibility of using a previously unused method based on registration of the seismoelectric effect.

To observe it in the field, we used an experimental model of the device containing a two-channel signal amplifier $E(t)$ and $S(t)$ a microcontroller that calculates function (1) and a digital display. A 200 m long receiving line grounded at both ends was used as sensors of electric field signals (figure 1). Seismic signals were received by a standard seismic receiver of the brand GS 20 DX.
The work was carried out at the end of July 2014, 2015, and 2016 on the Bystryanskaya and Novo-Mikhailovskaya areas of the above-mentioned field, well explored by geophysical methods and verified by boreholes. The gas depths are 1800 and 2000 m, respectively. Figure 2 shows the envelopes of the KVK RES (0) at the control points (in figure 2a - the center of the deposit in the region of 3000 m; in figure 2b - at the origin) along the observation profile. Based on these data, we can conclude that the presence of gas deposits in both areas clearly differs by the coefficient RES (0). The physical basis of the seismoelectric effect is the generation of electric charges by a gas reservoir under the action of external seismic disturbances.

The first publications on the seismoelectric effect in rocks were made back in 1939 by Ivanov [10]. Today, a large number of scientific articles are known, including monographs on the interaction of electric and seismic fields in rocks. In [11], a physical interpretation of field observations on Bystryanskaya area was given with more detailed measurements along one of the profiles passing...
through the anomalous zone of the gas reservoir. Hypothetical design of a hydrocarbon reservoir is modeled by a capacitor which is filled with a porous semiconducting medium with a complex parameter ε2. It was shown in [11] that when a seismic shock with a pressure ΔP is applied to a gas layer, an electric field with the intensity of its horizontal components can be detected on the Earth’s surface:

$$E_x = \frac{\varepsilon_2 \cdot \tau_1 \cdot E_0 \cdot \Delta P}{4\pi \cdot \varepsilon_2 \cdot p} \cdot \phi,$$

(2)

where $E_0$ – static electric field in depth $h$; $\tau_1$ – shock pulse duration; $p$ – reservoir density;

$$\phi = \sum_{i=1}^{n_x} \sum_{j=1}^{n_y} \frac{(x - x_i) \cdot dx \cdot dy}{\left[(x - x_i)^2 + y^2 + h^2\right]^{3/2}},$$

(3)

- geometric coefficient taking into account the density of distribution of electric charges over the cross section of the reservoir.

Here $x_i$, $y_j$ are the current coordinates of the emerging electric charges on the cross-sectional area of the reservoir; $h$ is the depth of its position; $E_0$ is the intensity of the static electric field of the Earth at a depth of $h$. In relation to the problem of forecasting a methane explosion in mines, the results described above can be transferred to an underground drift, replacing the reservoir gas in the calculations with a spherical one.

The implementation of this technology is represented by installing along the face of the electric field sensors, in the form of a wire grounded from both ends and geophones connected via wired or radio channels to the dispatcher’s computer. It is advisable to supplement such a system with antennas for receiving high-frequency electromagnetic waves generated by the formation of cracks in rocks in the USB range. When observing the SE effect, the cross-correlation coefficient (CCC) of acoustic and electrical noise is calculated, the maximum occurrence of which determines the place and time of accumulation of the gas bubble inside the face wall.

In conjunction with the other method mentioned above, the outputs of all sensors must be connected to the input of the neurocomputer, with which the module of the regressive mathematical model (RMM) is calculated for the connection of the probability of an explosion with the parameters of the controlled quantities - gas concentration, seismic-electric effect, stress-strain state (SSS) and the variance of acoustic and electrical noise. By comparing the PMM module with a given criterion, the time of the explosion is determined.

To implement the technology, it is necessary to conduct a study on the formation of a multivariate regression model of the onset of the moment and place of bifurcations, i.e. physical conditions for an explosion. The place and time of a possible explosion is determined modulo the probability function of its appearance $P$ as a regression mathematical model of communication:

$$P = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \ldots + \alpha_n X_n + \alpha_1^2 X_1 + \alpha_2^2 X_2 + \beta_1 X_1 X_2 + \beta_1 X_1 X_3 + \ldots,$$

(4)

where $X_1, X_2, \ldots, X_n$ – indicators of all used sensors; $\alpha_1, \alpha_2, \ldots, \alpha_n, \beta_1, \beta_2, \ldots, \beta_n$ – regression coefficients calculated through theoretical models of the connection of the probability of an event with the corresponding controlled parameter. These coefficients are also refined as a result of a survey of specialists and observation experiments. The program is put into operation using a trained neurocomputer.

The whole system works as follows. All sensors are mounted on the walls of the mine and are connected by underwater communication lines or via radio with a computer. To obtain the LIL between electromagnetic and acoustic noise in the frequency range 0.1 - 20 Hz, a two-channel circuit is used, in which, after amplification through the switch, both signals are converted into a digital stream and then simultaneously sent to RAM, after which they are transmitted to the microprocessor, to the input of which from the block digital data on the variances of both noise. The computer is configured to recognize
the place and time of a rock strike by a mathematical model (4). The place of a possible explosion is determined by the number of the system of sensors located along the face, for example, through a distance of 100 - 200 m, and the time of the event is modulo the regression function (4). According to the scientific press in mines, usually before an explosion, all types of sensors show a minimal signal, including the function module (4). After the silence mode, a blow can occur in a few tens of seconds. In any case, the maximum and minimum indicators (4) are the criteria for the probability of an impact.

An integrated approach and assessment of the possibility of a rock strike and explosion significantly increases the degree of work safety, especially in coal mines, given the fact that the most informative criteria - LIL and SSS have not been used anywhere before.

The problem of rock impact prediction is one of the most pressing problems of underground technologies and can only be solved by a set of methods - gas, seismoelectric, seismic, radio wave with the addition of monitoring the stress-strain state of the face walls.

An important factor is the transmission of messages from the excavated mine workings, in which, due to space limitations, it is impossible to deploy long electromagnetic antennas, while all other means of communication, primarily wired ones, can be destroyed. The solution to the problem may be a seismic communication channel developed by the authors, which does not require large-sized antennas for transmitting a message.

Upon the observation of a gas condensate field by the seismoelectric method in the noise fields of the Earth, the results of which are described in the article, it is advisable to test this method to solve the problem of earlier detection of methane accumulation and taking measures to prevent the consequences of its explosion.

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