On the possibility of predicting rock burst in mines by the seismic-electric method

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Abstract The article discusses a method for predicting a methane explosion in underground workings by observing simultaneously electrical and acoustic noises of the Earth on the surface of a mine field, highlighting their mutual correlation function. When used in the observation of acoustic noises by three-coordinate seismic receivers in two spaced along the Earth's surface, an algorithm for determining the coordinates of the expected explosion site is described. The results of field tests of the method at the Minusinsk gas condensate field are presented.

1. Introduction
Rock burst is one of the most dangerous phenomena that takes the lives of many people and is still unpredictable. It is caused by the accumulation of methane in rock cuttings and a sudden release through cracks in it. In science, there are different points of view on the reasons for the appearance of these “gas bubbles”.

When a certain level of pressure in the bubble is exceeded, gas begins to intensively penetrate into the mine working through the existing cracks, expanding them, and at a certain pressure, an abrupt rupture of the rock occurs, simultaneously causing an electric discharge such as lightning.

Back in the 50s of the 20th century, Professor A. A. Vorob’yov at the Tomsk Polytechnic Institute carried out a theoretical research and experimental work was carried out in Kamchatka to study the phenomenon of electric discharges in rocks during earthquakes [1].

The physics of this phenomenon is associated with the rupture of the electrical forces of cohesion between particles of a crystalline rock. Modern tools for forecasting rock bursts are based on monitoring the gas content in mine workings using stationary and portable gas analysers, as well as observing seismic conditions.

This technique is ambiguous in predicting the time and location of an accident, as methane may come from coal. Powerful ventilation, as a rule, copes with the gas emitted by the rock, but does not determine the moment of the explosion of the accumulated methane in the gas bubble.

In [2], the issues of assessing the rock burst hazard by observing seismoacoustic activity are discussed in sufficient detail. According to these data, a precursor of a possible explosion is the impulsive nature of seismic signals, the appearance of which is due to the appearance of cracks in the rock under gas pressure.

The frequency of occurrence of impulses in shock hazardous areas varies from 240 to 80 imp / min. Thus, their frequency range - the lower limit is from 6 to 1.5 Hz can be estimated, the upper one is determined by the steepness of the fronts of these impulses, and in fact, by the frequency response of the geophones used, i.e. about 500 Hz.
Other well-known forecasting methods include a method for measuring the electrical resistance of a rock, which is widely used in geophysics for geo-mapping.

As the pressure increases, its electrical resistance increases and, as noted in [3], as the impact approaches, this parameter can change abruptly.

Another prediction method is to observe the amplitude of electromagnetic radiation, the direction of which serves as an indicator of the rock burst hazard.

In general, these methods can provide a sufficiently large amount of information to determine the place and time of the possibility of an explosion. However, for the creation of automated monitoring of the rock bumps forecast, the listed methods have significant drawbacks - this is the complexity of the hardware implementation in the conditions of operating mines. Low noise immunity against industrial noise, since the noise of operating mechanisms and machines overlaps the range of noise signals useful for observation.

Based on the experience of work on seismoelectric phenomena in hydrocarbon fields [4], a new parametric method for predicting the location and time of an expected rock burst is considered below. In order to turn a guess into a functioning control complex, it is necessary, in addition to theoretical prerequisites, to conduct serious experimental research and instrumental research.

Among the specialists dealing with this problem, there is a well-founded view of this problem as a spontaneous event caused by the escape of gas from the mantle [5]. In this case, the process is accompanied by deformation of the rock, the appearance of cracks through which the gas exit channels are formed and expanded. The appearance of cracks in the crystalline rock causes the phenomenon of electrostatic discharge, which causes the explosion of the gas flow.

2. Materials and methods

Below, we will consider a possible way to track the occurrence of rock bumps and determine their coordinates, which consists in the fact that sensors of the seismic-electric effect are located on the Earth's surface or in worked-out drifts so that information from them comes from the entire mine field.

This device includes a receiving electrical line with grounding at the ends, connected to a receiver of electric field noise signals and at least two three-axis geophones spaced along the shaft surface, connected to a radio station to transmit noise seismic signals along three orthogonal components to the central processor.

![Image of a two-dimensional problem of determining the location of a gas bubble according to the data of noise signals taken from two geophones.](image-url)

**Figure 1.** A diagram of the implementation of a two-dimensional problem of determining the location of a gas bubble according to the data of noise signals taken from two geophones.
As an example, let us consider a two-dimensional problem of determining the location of a gas bubble from the data of noise signals taken from two geophones in figure 1. The figure shows a diagram of the implementation of this method: the surface of the Earth above the mine - 1; mining - 2; gas bubble - 3; transceiver antenna - 4; earthing switches - 5; seismic receivers - 6, 7; three-dimensional vectors for receiving seismic noise signals - 8, 9; measured angles of arrival of seismic signals – α, β, γ; spacing of geophones along the surface – C; measured distances to the explosion site – A, B; electrical noise signal – E(t); noise electric field lines – E.

With known measured angles of arrival of the seismic wave α, β, γ and the distance between the geophones - C, the sides of the triangle are determined as [11]:

\[
\begin{align*}
A &= C \frac{\sin \alpha}{\sin \gamma}, \\
B &= C \frac{\sin \beta}{\sin \gamma}, \\
\sin \alpha &= \frac{R_{2x}}{R_1}, \\
\sin \beta &= \frac{R_{x2}}{R_2}, \\
\gamma &= 180 - (\alpha + \beta).
\end{align*}
\]

The angles of a seismic wave arrival are determined through the cross-correlation coefficient (CCC) between E and S:

\[
\cos \alpha = \frac{R_{x1}}{R_1}, \quad \cos \alpha = \frac{R_{x2}}{R_2},
\]

where \( R_1 = \sqrt{R_{x1}^2 + R_{z1}^2} \), \( R_2 = \sqrt{R_{x2}^2 + R_{z2}^2} \).

Here:

\[
\begin{align*}
R_{x1} &= \frac{1}{T} \int_0^T E(t) S_{x1}(t - \tau) \cdot dt, \\
R_{z1} &= \frac{1}{T} \int_0^T E(t) S_{z1}(t - \tau) \cdot dt, \\
R_{x2} &= \frac{1}{T} \int_0^T E(t) S_{x2}(t - \tau) \cdot dt, \\
R_{z2} &= \frac{1}{T} \int_0^T E(t) S_{z2}(t - \tau) \cdot dt
\end{align*}
\]

where \( R_x \) and \( R_z \) – are the CVC of the noise signals of the seismic \( S(t) \) and the electric field \( E(t) \) respectively, along the x and z coordinates.

Note that the signals of the electric field of the gas bubble \( E(t) \), due to the longer wavelength, are integral throughout the mine field and are reference for all measurements, providing detuning of the electrical noise of the gas bubble from sources of other noise signals. In this case, the appearance of electric field noises is caused by the vibration of a gas bubble due to natural seismic disturbances of the Earth, mechanisms operating in the mine, as well as electrical discharges during the breakthrough of accumulated gas through cracks in the rock.

![Figure 2](image-url) The dependence of the electric field strength \( E_x \) in relation to \( E_N = 1 \mu V / m \) on the Earth's surface from the depth of the position of the gas bubble \( h \) and its volume at a pressure of 1 Pa.
The advantage of the described method is the ability to continuously monitor the threat of a rock burst without moving the sensors over the field surface.

3. Results of field tests
In July 2019, the first field experiments were carried out at Bystryanskaya space to test the possibilities of estimating coordinates by a noise source. The rock burst was simulated by the excitation of seismic waves by a pulse non-explosive source Yenisei KEM-4 with an impact force of 100 tons with a pulse duration of 5 ms and a repetition period of 10 s.

The source was located near a gas reservoir located on the indicated area at an average depth of up to 1800 m. Two observation points with a three-coordinate seismic receiver and an electric receiving line 200 m long were in the area of well 8 at a distance of 550 m from the source, and at a distance of 1000 m between themselves. that the seismic shocks reflected from the gas reservoir together with the electric field caused by them will simulate noise similar to those generated by a gas bubble before a rock bump. The observations were carried out in time separately at each point by the same receiving complex. The cross-correlation coefficient (CCC) of seismic and electrical signals was measured along three coordinates of the seismic receiver with averaging 10 source shocks along each of the coordinates $R_X, R_Y, R_Z$. On the X coordinate, the geophones were oriented to the North. After measurements, the CCC module was determined:

$$\bar{R}_{ES}(0) = \sqrt{R_X^2 + R_Y^2 + R_Z^2}$$

And its angular direction, indicating the place of emission of the seismic signal, excited by the source KEM-4 (table 1).

**Table 1.** Angular direction, indicating the place of emission of the seismic signal, excited by the source KEM-4.

| $N_T$ | $R_X$ | $R_Y$ | $R_Z$ | $\bar{R}_{ES}$ |
|-------|-------|-------|-------|-----------------|
| 1     | 0.14  | 0.08  | 0.235 | 0.28            |
| 2     | 0.15  | 0.01  | 0.02  | 0.14            |

It can be seen from table 1, at point 2 the values of CVC, especially along the coordinates Z and Y, turned out to be significantly less than at point 1, which is apparently associated with a high level of industrial noise from the power line passing in this area. For this reason, let us estimate the coordinates of the seismic signal reflection point according to the data of point 1.

**Figure 3.** Geometry of emission and reception of seismic signals: 1 - surface of the earth; 2 - gas reservoir; 3 - receiving the CCC module; 4 - electric dipole; 5 - a source of seismic shocks.
From figure 3 it is possible to estimate the angles of direction of passage of the seismic signal.

\[ \tan \varphi_{11} = \frac{\sqrt{R_{x1}^2 + R_{y1}^2}}{R_{z1}} = 0.68 \]; \quad \varphi_{11}=30^\circ \quad (5) 

The location point of the seismic wave source 5 was at a distance of 550 m from the observation point (4). According to the formulation of the semi-active seismic-electric method in 2017, the gas reservoir at the point of position was at a depth of \( h = 800-1000 \) m. The slope angle \( \varphi \) of the CCC vector module

\[ \bar{R}_1 = \sqrt{R_{x1}^2 + R_{y1}^2 + R_{z1}^2} \] is determined through the ratio:

\[ \tan \varphi = \frac{\sqrt{R_{x1}^2 + R_{y1}^2}}{R_{z1}} = \frac{d}{h} \quad (6) \]

In accordance with the table 1, \( \tan \varphi = 0.34, \varphi = 30^\circ \), whence \( d = h \tan \varphi = 272 - 340 \) m.

Thus, according to these data, the distance between the observation point (4) and the sources of seismic shocks was \( 2d = 540 - 680 \) m, which, taking into account the approximate velocity of propagation of longitudinal seismic waves \( V_p = 200 \) m/s, taken when assessing the depth of the reservoir position \( h \), we can consider that the experiment gave positive results. This means that in real conditions, at a known depth of controlled mine workings, one observation point is sufficient to determine the location of a rock burst. Thus, the first full-scale experiment confirmed the theoretical foundations of the seismic-electric method for forecasting rock bursts.

4. Conclusion

The problem of rock burst prediction is one of the most pressing problems of underground technologies and can be solved only by a set of methods - gas, seismic, seismic-electric, radio wave and other methods. Based on the observation of a gas condensate field by the seismic-electric method in the noise fields of the Earth, the results of which are described in [4, 10], it is advisable to test this method to solve the problem for the earlier detection of methane accumulation and taking measures to prevent the consequences of its explosion. The main advantage of the seismic-electric method in comparison with the acoustic one is a higher noise immunity against industrial noise and an additional information parameter of the presence of a gas accumulation. It is advisable to carry out experimental verification in a gas field with the excitation of a productive formation by a pulsed non-explosive source of seismic waves.

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