Improvement of technology and procedures of local rockburst hazard control

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Abstract. At some rockburst-hazardous deposits in Russian Far East and on the Kola Peninsula, the measurement of acoustic emission parameters is performed, and new data are obtained on hazardous features of confining pressure in different sites of mine fields. The measurement procedure is developed for local ground pressure control Prognoz L, and additional rockburst hazard criteria are substantiated for underground mines.

1. Introduction

Prediction and prevention of hazardous events caused by confining pressure critically needs reliable and real-time information on geomechanical behavior of rock mass. Such information can be obtained using many approaches, including geophysical methods and measurement facilities [1]. Microseismic and geoacoustic methods are commonly used to this end. The latter method allows both local and regional control over rock mass condition. The method uses the experimentally observed and theoretically investigated phenomenon of acoustic emission (AE) which accompanies mechanical loading and destruction of rocks [2].

Developed at the Institute of Mining, FEB RAS, rockburst hazard control system Prognoz-L [5] enables recording of more parameters of AE as well as processing and comprehensive analysis of the acquired information. This tool has proved its efficiency in real-time geomechanical control of rock mass behavior.

The tool is effectively employed in underground mines such as Nikolaevsky, Yuzhny and Silinsky of Dalpolimetal Mining and Metallurgical Company, Aikhal and Internastionalny of ALROSA, Gluboki of Priargunsky Mining and Chemical Union, as well as United Kirov Mine and Rasvumchorr of Apatit.

2. Rockburst hazard control system

Portable local rockburst hazard control facility Prognoz L is composed of a sensing device and a measurement block (Figure 1a). By the results of review of modern acoustic recorders, laboratory-scale and field test data, the sensing device for Prognoz L is chosen to be accelerometer AR99-1000 manufactured by GlobalTest in Saratov, Russia (Figure 1b).

The measurements and operation history of the facility is stored on micro-SD flash card. The card interface is provided by microcontroller STM32F405 which enables reading and recording of data without using the computation core.
Figure 2 presents the windows of settings and measurements with user’s and engineering menus. Before AE measurement is started, the settings of the device are adjusted: date/time, digital recording, volume level, etc. frequency/amplitude/time filter of AE pulse detection. For visual control, some parameters are displayed in real-time mode.

![Figure 2](image)

**Figure 2.** Prognoz L setting: (a) main window; (b) AE measurement results; (c) user’s menu; (d) engineering menu

The local control facility Prognoz L uses some algorithms meant for detection of useful AE signals and for filtration of various-nature noise.

The rock mass behavior assessment procedures implemented in Prognoz L use such criteria as AE intensity free from visible technological impact, $N_{AE}$, and amplitude distribution index $b$ [6].
intensity $N_{AE}$ allows judging on ultimate loading reached in rock mass. The amplitude distribution index $b$ characterizes instability of deformation and increment in high-energy pulses, and is given by:

$$b = \log \frac{N_{AE}^1}{N_{AE}^2}/\log \frac{A_2}{A_1},$$  \hspace{1cm} (1)

where $b$ is the ratio of acoustic pulses of different amplitude (energy); $A_1$ and $A_2$ are the tool sensitivity limits; $N_{AE}^1$ and $N_{AE}^2$ are the AE intensities at different limits.

The AE intensity unit per time is assumed as N15, which is AE activity in a 15 second-long interval. The critical values of this criterion vary subject to geology of test object, geological and geotechnical conditions, and individual features of a specific mine. These values are taken from the range of N15 = 4–13 pulses.

Alongside with $N_{AE}$ and $b$, the rock mass behavior assessment can use additional AE parameters such as AE spectrum characteristics.

The mines operating the control facility provide the Institute with the actual data of measurements taken in operating tunnels having signs of higher confining pressure. These data are processed with a view to adjusting the rockburst hazard criteria dependent on properties of rocks to accumulate and release potential energy in the form of brittle and explosive fracture.

Local controller Prognoz L implements algorithms of natural AE signal identification on the industrial noise background.

The AE signal identification criterion is a parameter named as MARSE—measured area under signal epure, which is an abstracted analog of the AE pulse energy. MARSE is simultaneously sensible to amplitude and duration of a signal, which improves AE identification reliability.

MARSE at the time $t_i$ (quantum $i$) is calculated in the previous time window of a fixed length $Y$. At each subsequent calculation, the MARSE value shifts the previous time window by 1 quantum and is calculated again from the formula:

$$S_i = \sum_{j=1}^{i} A_j,$$  \hspace{1cm} (2)

where $S_i$ is the calculated area of the signal within the current time window of MARSE; $A_i$ is the discrete value of the signal amplitude within the current time window.

Every next signal is recorded as the parameter $S_i$ exceeds a threshold value $S_{\text{threshold}}$. At all stages of the algorithm, the value of $S_{\text{threshold}}$ is subjected to adaptive adjustment in conformity with the change in the peak-factor in the signal–noise record. Om the conditions of variation in the noise component of the signal, it is continuously required to adjust $S_{\text{threshold}}$. The local rockburst hazard control facility can automatically select the threshold (function of stepped integrating of MARSE):

$$S_{\text{threshold},i} = A + B \cdot \sum_{j=i-Y}^{i} S_j,$$  \hspace{1cm} (3)

where $S_{\text{threshold},i}$ is the function of change in the adaptive threshold; $S_i$ is the value of MARSE at a $j$-th count; $A$, $B$ are the coefficients (settings) found empirically to adjust sensitivity of the AE detection device; $Y$ is the length of the calculation window.

The algorithm ensures effective detection of natural AE pulses against frequent noise and enables high-performance ge acoustic control in the conditions of intense industrial interference.

Brittle fracture of rocks is a multi-stage process, which sometimes impairs reliable estimate of rockburst hazard using criteria which only include quantification and ratio of AE signals of different energy. When the stage of stead-state energy accumulation changes into the stage of main fracture growth between microfractures [3, 4], the rockburst hazard risk jumps even at low value of the quantitative index. Put it otherwise, the rockburst hazard assessment should take into account the total energy coefficient of recorded AE signals within a single measurement taken by the local control.
facility even in case when measurements are taken immediately one after the other at the same location.

According to (4) summation is carried out over the value of MARSE (2) of each recorded AE pulse within one measurement taken by the local control facility:

\[ S_{\text{eng}} = \sum_{j=1}^{k} S_j, \]

where \( S_{\text{eng}} \) is the total energy coefficient; \( S_j \) is the calculated area of the signal in the current window of MARSE.

The use of a single sensing device in the local control facility limits the location capacities in terms of the natural AE pulses and their energy. For this reason, the additional criterion of geomechanical behavior in rock mass can be the parameter MARSE described above.

Figure illustrates measurement of AE parameters in Zvezda site on level +150 m, haulage ramp 170/10 in Yukspor branch of United Kirov Mine. The measurement data are compiled in Table 1.

![Figure 3. Location of local rockburst hazard control facility (black point) in Yukspor mine, level +150 m, haulage ramp 170/10 on November 17–21, 2017.](image)

**Table 1.** Measurement data on AE in Yukspor mine, level +150 m, haulage ramp 170/10

| No. | Date  | Time  | t, min | Threshold, dB | Number of pulses per channels | Average activity \( N_{15} \) | Total energy coefficient, units | Rockburst hazard category |
|-----|-------|-------|--------|--------------|------------------------------|-------------------------------|-------------------------------|--------------------------|
| 1   | 17.11.17 | 11:11 | 10     | 25           | 33                           | 682                          | 338                          | 17.04                    | 249499923                | Hazard                   |
| 2   | 17.11.17 | 11:29 | 10     | 25           | 33                           | 576                          | 227                          | 14.4                     | 148074464                | Hazard                   |
| 3   | 21.11.17 | 10:55 | 10     | 25           | 33                           | 114                          | 45                           | 2.85                     | 23271157                 | Nonhazard                |
| 4   | 21.11.17 | 11:05 | 10     | 25           | 33                           | 107                          | 46                           | 2.67                     | 22487922                 | Nonhazard                |
The estimated rockburst hazard of the test site was proved by researchers from the Saint-Petersburg Mining University by estimates of damage in boreholes drilled across the maximal principal; effective stress (vertically in the roof) as well by the visual inspection. On November 17, 2017, the facility recorded the Hazard category and the quantitative index exceeded the maximum value of the criterion by 3 times. Distressing drilling was undertaken and AE activity essentially lowered on November 21, 2017, but the category of the site remained Hazardous. The estimate was proved by new and intense fracturing and spalling.

Accordingly, we can assume that as rock mass disintegration changes to the stage of large fractures and their clustering, the quantitative index may lower while the probability of a geodynamic event remains very high. It is the situation when we need an additional criterion based on the total energy coefficient of AE pulses per unit time. For enclosing rock mass of Yukspor deposit, this coefficient makes 550000 within 15 second-long interval.

Similarly, in Nikolaevsky mine, during drivage of Severny 4 ramp on level -420–406 m, the controller recorded increased acoustic activity, and intense fracturing was observed in rhyolitic tuffs and tuff breccias. These rocks are assumed as jointed and moderate stable. The hardness factor on Protodyakonov’s scale is 12–14. Geodynamic activity in that test site lasted for more than 10 days since April 18, 2012. Table 2 presents the measurement data for the increased acoustic activity period on ramp Severny 4.

Table 2. Measurement data on AE in Nikolaevsky mine, ramp Severny 4 on level -420–406 m

| No. | Date Time       | t, min | Threshold, dB | Number of pulses per channels | Average activity $N_{15}$ | Total energy coefficient, units | Rockburst hazard category |
|-----|-----------------|--------|---------------|-----------------------------|----------------------------|---------------------------------|---------------------------|
| 1   | 18.04.17 (10:13)| 5      | 10 19         | 155 138                     | 8.15                       | 8862057                        | Hazard                    |
| 2   | 18.04.17 (10:21)| 5      | 10 19         | 291 194                     | 15.31                      | 8285022                        | Hazard                    |
| 3   | 21.04.17 (10:28)| 5      | 10 19         | 301 248                     | 15.84                      | 7461657                        | Hazard                    |
| 4   | 18.04.17 (10:50)| 5      | 10 19         | 432 409                     | 22.73                      | 28703698                       | Hazard                    |
| 5   | 18.04.17 (10:55)| 5      | 10 19         | 895 879                     | 47.10                      | 122080283                      | Hazard                    |
| 6   | 18.04.17 (11:01)| 5      | 10 19         | 698 662                     | 22.73                      | 49515662                       | Hazard                    |
| 7   | 19.04.17 (10:48)| 10     | 10 19         | 336 287                     | 8.84                       | 16400769                       | Hazard                    |
| 8   | 19.04.17 (11:00)| 10     | 10 19         | 578 520                     | 15.62                      | 33033287                       | Hazard                    |
| 9   | 19.04.17 (11:11)| 10     | 10 19         | 537 469                     | 14.51                      | 26736665                       | Hazard                    |
| 10  | 19.04.17 (11:23)| 10     | 10 19         | 548 462                     | 14.81                      | 26661562                       | Hazard                    |
| 11  | 19.04.17 (11:33)| 10     | 10 19         | 245 209                     | 6.62                       | 7886213                        | Hazard                    |
| 12  | 19.04.17 (11:46)| 10     | 10 19         | 345 126                     | 9.32                       | 33261050                       | Hazard                    |
| 13  | 25.04.17 (09:44)| 10     | 10 19         | 117 111                     | 2.92                       | 9955762                        | Nonhazard                 |
| 14  | 25.04.17 (09:54)| 10     | 10 19         | 114 109                     | 2.85                       | 8309991                        | Nonhazard                 |
| 15  | 25.04.17 (10:04)| 10     | 10 19         | 112 110                     | 2.80                       | 6605564                        | Nonhazard                 |
| 16  | 02.05.17 (09:49)| 10     | 10 19         | 133 129                     | 3.32                       | 18540190                       | Nonhazard                 |
| 17  | 02.05.17 (10:00)| 10     | 10 19         | 94 92                       | 2.35                       | 7097158                        | Nonhazard                 |
| 18  | 03.05.17 (13:30)| 10     | 10 19         | 70 63                       | 1.75                       | 4255447                        | Nonhazard                 |

The rockburst hazard of the latter test site between April 18 and May 2, 2017 was confirmed by automated ground control system Prognoz-ADS which detected the acoustically active zone. Signs of increased confining pressure were present in the roof and sidewalls in underground excavations. For enclosing rock mass composed of rhyolitic tuffs and tuff breccias at Nikolaevskoe deposit, total index MARSE is 175000 within 15 second-long interval.
3. Conclusions
1. Portable geacoustic rockburst hazard control facility Prognoz L has been introduced in operation in mines. This facility allows recording and determination of AE parameters even in the conditions of high industrial noise.
2. The investigation of rockburst hazard assessment using the local controller in combination with automated ground control system has been performed.
3. For the proposed facility, efficient algorithms and software are developed to ensure recording of AE signals in operating mines, determination of the main AE parameters (AE intensity, AE signal frequency, as well as duration, amplitude and relative energy characteristic of AE events, etc.) and the in-depth analysis of the geomechanical control results. The total energy coefficient of AE pulses is analyzed. From the analysis results, preliminary values of the coefficient $S_j$ are obtained for specification of the additional rockburst hazard criterion for operating Nikolaevsky mine.

References
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