Selection of criteria to estimate deformation of kimberlites in seismic-acoustic monitoring of Mir pipe

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Abstract. In terms of the seismo-acoustic monitoring in Mir Mine, criteria are proposed to estimate deformation of the ore body. The relationship between the linear size of fractures and the intensity of radiated energy is revealed.

1. Introduction
Geotechnical estimation is an important part of mineral mining process. The estimation should include basic physical and dynamic events in rock mass and the accepted method of mining [1].

Mines of ALROSA Company use geotechnical control systems based on the:
—estimation of regional-scale geotechnical risks inside the area of a mineral deposit, considering water bodies, and local-scale risks within a mine field;
—routine monitoring of pre-accident signs towards prompt precaution and prevention;
—adjustment of control system with regard to variation in mining technology and mine-technical conditions;
—real-time visualization of monitoring data and storage in data bases of geotechnical service and supervision office;
—improvement of control procedures and refinement of hazard criteria for each specific deposit with regard to a mining method.

On the ground of the listed principles, the Company has developed a selection algorithm for optimized control, including research and development, for each deposit. For example, the integrated monitoring of diamond-bearing kimberlite mining in Mir Mine uses seismo-acoustic and surveying control, and measurement of displacements by deep-seated survey plugs.

In practical seismometry, coordinates of seismic events are determined by the first arrivals of P- and S-waves, while mechanism and energy of events are defined by the duration and spectrum of seismo-acoustic signals [2]. However, interpretation of seismic signals allows indirect estimation of processes running in rocks, by inversion of seismograms. A tectonic shear or an explosion can be described using force dipoles, whereas it is difficult to represent failure of interchamber pillars or deformation of backfill stoping belts by equivalent forces based on seismograms.

Similar problems arise in assessment of state of kimberlite ore featuring low strength characteristics and incapable to accumulate considerable stress for the generation of rock bursts.

In this connection, it is an important task of mine safety to determine a zoning criterion to divide rock mass into stable and failure-hazardous areas.

2. Key points of monitoring system selection for Mir kimberlite pipe
The framework of the integrated monitoring system for kimberlite mining includes:
—Mir kimberlite strength is from 45 to 60 MPa, peak seismic wave velocity reaches 1700 m/s;
the optimal choice of sensor spacing in the network depends on the signal sampling rate with regard to the wave velocity:

—failure of kimberlite on the same level in a mine may be both brittle and elastoplastic. In view of geometry and block structure of the ore body and enclosing rock mass, it is inexpedient to record initial stages of fracturing in a seismic range to 800 Hz. The reliable location of natural seismic emission which points at failure requires that the recording frequency band is 0.5–12 kHz;

—an additional estimate of deformation process intensity is drift velocity of a cluster of seismic events, which is reflective of the area of the fracture growth in rock mass;

—it is advisable to confirm coordinates of a localized deformation zone by check measurements in local sites using a portable device (rock mass sounding). Susceptibility of rock mass to rockbursting can be estimated by acoustic emission (AE) only base on recording of brittle failure events with weak energies without artificial activation of acoustic processes;

—number of AE impulses recorded within a certain time interval, density of spatial distribution of AE sources, as well as energy and amplitude of AE signal are the basic source data for the determination of a critical isoline and estimation of deformation processes.

3. Selection of monitoring system

Using the above methodological framework, it has been decided to carry out monitoring in Mir Mine based using methods of seismoacoustic and Prognoz-ADS system that detects hazardous events due to rock pressure in underground mineral mining [3].

The system includes spatially distributed piezo-electric g-meters–geophones to detect and measure impulses of natural AE. The data on seismoacoustic events (SAE) are accumulated in data base for the further analysis and interpretation. The built-in software enables detection and recording of acoustic events, and determines parameters of acoustically active zones, which allows assessment of geomechanical behavior of rocks. The measurement data are used in 2D or 3D mapping of the acoustic activity of rock mass.

By analyzing regular patterns of distribution of AE sources, areas with high energy and density of AE are delineated and rated in terms of potential hazard [4].

The basic signs of an AE source are: concentration and localization of AE events; frequency and persistency of acoustic activity periods, velocity, volume, total energy and migration direction of acoustically active zones, distance between a source and exposed rocks, etc. These characteristics are experimentally determined at each specific deposit.

For the conditions of Mir kimberlite pipe, the optimal parameters of the network of seismoacoustic sensors, their number and frequency bands for reliable recording of events which point at failure in kimberlite have been found from in situ experiments. The resultant seismoacoustic control system covers the zone of a crown pillar below the open pit bottom with an area of 65 thou m². With the spacing of 120 m, the error of SAE coordinates is not more than 5 m even in the complex structure rock mass.

4. Seismoacoustic event criteria

The seismoacoustic (geoacoustic) method has a high resolution capability as it allows recording of weak elastic impulses (with an energy from 1 J and above) emitted at the early stages of deformation in rocks. In this case, it becomes possible to monitor the process of initiation of failure zones starting from the beginning, which essentially improves reliability of prediction of hazardous events due to rock pressure and offers some time for precaution decision-making and implementation.

The analytical research involves a simplified algorithm of assessment of acoustic events by the impulse recording time, and by signal duration and amplitude; later on, these data are used to determine energy and coordinates of AE source as well as basic characteristics of signals to distinguish between the natural and induced AE events.

As a result, new data on interaction between deformation processes in roc mass subjected to critical stresses and variation in acoustic field parameters have been obtained.
Earlier (since 2010) monitoring of the kimberlite pipe was based on the measured displacements of plugs installed in the roof and floor of underground excavations. The comparison of the subsidence measurements and the acoustic activity characteristics over the period from April to September 2016 proves their good agreement.

A complementary control technique was chosen surveying by plugs in roof rocks and estimation of convergence in underground excavations.

The analysis of the composite map of subsidence and acoustic emission in 2016 shows that the boundaries of different damage zones agree well with the subsidence in the center of the crown pillar.

For the visualization of the process of deformation development, the crown pillar along its height (interval of actual elevations 190–230 m) was divided into equal vertical cells with an areal size 20×20 m. Then, inside these cells, energies of all AE events recorded in 1–20 and 20 June–10 July were summed up. Plotting of the isolines of the total energy per unit cell volume allowed tracing intensive failure at ore and rock mass interface over the period from June to July 2016. This situation was expectable and connected with the accepted mining technology, difference in strength characteristics of ore body and rocks and high dislocation and damage of the ore body. Large-block undamaged rock mass is in the stress concentration zone adjoining the ore and rock mass interface.

It is worthy of mentioning that such approach provided a qualitative picture of deformation even in the regions beyond the coverage of the earlier net of plugs ‘tied up’ with underground excavations.

Aiming to determine safety criterion, it was decided to estimate interrelation between AE energy and sizes of induced joints. The subvertical monotonous drift of AE signal coordinates in the crown pillars was considered formation of failure plane or fracturing plane.

The revealed regularity in the change of actual elevations of AE coordinates connected with the level of emitted energy points at the initiation of potentially hazardous failure processes in kimberlite rock mass.

From the analysis of characteristics of AE signals recorded in the crown pillar under the open pit mine bottom in 2016, the linear fracture size \( Lm \) has been related with the AE energy intensity \( E(J) \) in kimberlite rock mass. This relation at the approximation factor 0.92 can be represented by the exponential and polynomial functions:

\[
E(J) = 654.66 \times e^{0.351 \times Lm},
\]

\[
E(J) = 159.82 \times Lm^2 - 450.09 \times Lm + 1358.2.
\]

In this manner, on the ground of the revealed regularities, it is possible to detect signals of potentially hazardous events and to model failure planes in rock masses. Localization of fracturing zones is based on the direct monitoring carried out by geotechnical service in mines using the methods of visual control by portable seismoacoustic devices, which enables more accurate delineation of hazardous zones and estimation of their effect on mining safety.

5. Conclusion

1. For the conditions of Mir kimberlite pipe, for the first time, the criteria and procedure have been developed for the detection of hazardous deformation in rocks using the geoacoustic method in the event of insufficient data on failure (brittle or elastoplastic).

2. Regarding the safety criterion, the interrelation has been revealed between the linear size of growing fractures and the intensity of emission energy in kimberlite rock mass.

3. Using the proposed package of predictive indicators of critical state by parameters and behavior of seismoacoustic emission in rocks enables the early-stage zoning of rock mass by the degree of damage and stress state estimation as well as later detection of failure stages with differentiation between natural and induced signals.

References

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