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Review of Studies of Mechanoelectrical Transformations in Rocks in Russia and Abroad

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Abstract. The problem of monitoring and forecast of dynamic manifestations of rock masses becomes immediate in the mining industry because of the growth of mining work intensity and changeover to the mining operations in deeper levels. The article presents a short review of the scientific works of foreign researchers for more complete and in-depth study of geophysical methods of control of the stress-strain state and bump hazard of rock masses.

1. Introduction

Undersurface mine development of solid minerals causes changes in the stress-strain state (SSS) of the rock mass and, as a consequence, geodynamic manifestations. This affects the safety of people, environment, industrial sites and mining operations. Development of changes in the SSS of the rock mass is the result of natural processes in the earth interior and man-made influences. The knowledge of the nature and degree of influence of the elements and processes of technology on the state of the rock masses and its response to this impact becomes especially important. One of the methods used in undersurface mine development of solid minerals is the technological explosion causing the rapid redistribution of the stress field in the rock mass. At this time the stress reduction in one area of the mass is accompanied by the increase in others. As a result of accelerated stress changes in the rock mass in the mine field, bump hazardous situation can occur. In this case, the technology of mining operations is the main man-made factor that provokes the geodynamic events in the areas of critical stress. Unloading of the mass in this way makes it possible to avoid geodynamic events in the field for a while.

Currently, the work on creation of change control information system of the stress-strain state of rock masses and bump hazard forecast is being carried out in the Electronics, Dielectrics and Semiconductors Lab, Tomsk Polytechnic University. The basis of this system is the phenomenon of the dynamoelectric energy transformations in the dielectric structures [1, 2]. Mechanoelectrical transformations are manifested in the form of electromagnetic signals, which can be detected using appropriate instrumentation. Under the laboratory conditions, theoretical and experimental research of the parameters of electromagnetic signals and electromagnetic emission characteristics of model samples and real surface rocks under uniaxial compression and deterministic impulse acoustic treatment are carried out. The stress-strain state change, electromagnetic signal parameters and electromagnetic emission characteristics are logically connected. The research has shown that the mechanoelectrical transformations may occur under thermal, acoustic, mechanical, chemical, radiation and other external influences.

Researches from different countries study geophysical methods of rock-bump hazard evaluation and control of the stress-strain state of rock masses due to the complexity of the object of study and the variety of tasks to be solved in geomechanics and geotechnologies.

2. Review of studies mechanoelectrical transformations

The phenomenon of EME (electromagnetic emissions) from rocks was discovered by J. Milne who reported at the end of the 19th century anomalous magnetic and electric phenomena accompanying an earthquake (Milne, 1890). Intensive research into EME from rocks has been conducted in many research centers since the early 1980s [3].

2.1. Theoretical work

Rabinovitch et al. (2000) attempted to explain the mechanism for EM emissions and concluded that following early pore closure, microcracking and possibly coalescence occurred, while just before peak stress was reached, the rock collapsed. A summary of information about the frequency and wavelength of EM emissions showed that their frequency range was 1 kHz (with a wavelength of 300 km) to 10 MHz (with a wavelength of 30 m) [4].

Goldbaum et al. (2001) identified four distinct EM emissions waveforms: short single pulses, a short chain of single pulses, an extended chain of pulses, and a new group, pulses along baseline voltage changes. Significant to their work were EM frequencies reaching 25 MHz (formerly believed to be only up to 10 MHz) [5].

Rabinovitch et al. (2001) continued investigating mechanisms for EM emissions and concluded that the mechanisms for the earthquake EM emissions were the same as for microfracturing in laboratory tests. They studied the Gutenburg-Richter type and Benioff strain-release relationship for earthquakes and found the relationship extended to the microlevel [6].

2.2. EM Source Mechanisms

In 1986 in the USA Brady and Rowell summarized four mechanisms that cause light to be emitted from fracturing rock: (1) rock fragments frictionally heated to incandescence, (2) electrostatic discharge produced by the deformation of piezoelectric minerals or charge separation on fractured surfaces, (3) plasmas produced by rapid and intense heating of rock material, and (4) excitation of the ambient atmosphere by particle (electrons or positive or negative ions) bombardment. Brady and Rowell concluded that the light emitted from test rocks in the laboratory was caused by excitation of the ambient atmosphere by particle bombardment [7].

In 1988 Chinese researcher, Zi-qiang et al. examined three sources of light: (1) heat radiation from friction, (2) electrostatic discharges produced by piezoelectric effects or charge separation on fractured surfaces, and (3) excitation of the ambient atmosphere by particle bombardment. Because light emissions were observed only at the moment when electrons struck air molecules, the authors concluded that the most likely source of EM emissions was excitation of the ambient atmosphere by particle bombardment [8].

2.3. Laboratory tests

Tuck et al. (1976) tested a cube of quartzite coupled with a quartz crystal to determine piezoelectric emissions when a 0.5-kg hammer was used as a seismic source. They concluded that no piezoelectric fabric was found; therefore, it would be difficult to use EM emissions for the exploration of ore bodies [9].

Nitsan (1977) fractured quartz crystals, tourmaline crystals, and quartz-bearing rocks and recorded EM emissions in the frequency range of 1 to 10 MHz. His interpretation of the source of the emissions was piezoelectricity [10].

Goncharov et al. (1980) tested several large (0.55 by 0.55 by 0.65 m) blocks of concrete containing pieces of granite by applying load and recording both EM and acoustic emissions as the concrete failed. They recognized the fundamental problem of simultaneously recording both EM and seismic emissions and concluded that the number of EM emissions decreased as their amplitude increased. They also found that the ratio of EM to acoustic emissions post-fracturing was 20:1. Prior to fracturing (initial loading), the ratio had been 7:1 [11].

In 1981, Bishop studied piezoelectric effects in quartz-rich rocks. Using a laboratory-designed system, he attempted to prove that the axis of the quartz crystals was a factor in EM emissions. He found that a relationship existed between EM emissions and predictions of the c-axis orientation in quartz crystals [12].

Hanson and Rowell (1982) tested quartzite from the Galena Mine. EM emissions peaked sharply below 40 kHz on three antennas, leading them to conclude that (1) fracture formation coincided with EM emissions, (2) EM emissions fell into a frequency range of less than 40 kHz, (3) EM emissions seemed to be directional, and (4) the amplitude of EM emissions seemed independent of stress, but not independent of stress drop [13].

Khatiashvili (1984) showed that as the size of fractured crystals increased, electrical potential also increased [14].

Zi-qiang et al. (1988) fractured granite in the laboratory and found that the most intensive light pulse and acoustic emissions were recorded simultaneously at the moment of rock fracture [8].

Weimin et al. (1991) fractured quartz, limestone, and granite samples and reported that recorded EM emissions were a result of rock fractures [15].

2.4. Earthquakes
Martner and Sparks (1959) noted electrical potential prior to the arrival of seismic waves at the surface of the ground. About 30 minutes prior to the arrival of main earthquake shocks, Gokhberg and Morgounov (1982) recorded EM emissions at frequencies of 27, 81, and 1.5 kHz and 1.63 MHz. Later, Migunov et al. (1984) documented EM emissions in the frequency range of 0.5 to 50 kHz that were associated with seismicity from earthquakes. Fujinawa and Takahashi (1990) observed EM emissions in the 0.01- to 12-Hz and 1- to 9-kHz frequency bands hours before earthquake activity in Ito, Japan. Fujinawa and Kumagai (1992) observed ultralow-frequency (0.01 to 0.6 Hz) to very low-frequency (1 to 3 kHz) electrical emissions before, during, and after volcanic eruptions [16].

2.5. Underground
Frid et al. (2000) continued their work in the laboratory and attempted to correlate EM emissions with crack dimensions. They found that the amplitudes of EM emissions and their changes with loading were independent of both tensile and shear failure and that they were dependent only on the area of the entire crack [17].

Frid (2001) recognized the value of using EM emission criteria to forecast rockburst hazards in coal mines by using the limiting value of broken coal volume, mine working width, coal seam thickness, and coal elastic properties [18].

Butler et al. (2001) conducted field studies at the Brunswick No. 12 Mine in Canada in an attempt to link EM emissions with seismic activity and also to delineate sulfide ore. They used various antennas covering a range of frequencies from 1 Hz to 4.5 MHz. They found that broadband EM emissions with frequencies up to 800 kHz could be induced by seismicity and blasting. However, results did not confirm that EM emissions preceded seismicity [19].

Vozoff (2002) attempted to demonstrate the use of EM monitoring as a warning system for roof failure in a large coal seam in Australia. He collected three complete datasets and concluded that of the three, one set coincided with a roof fall and was correlated with EM activity, one set might have had a “weak correlation at best,” and one set had no EM correlations with roof falls [20].

Research on the use of EME to monitor the level of hazard in headings has been conducted in several centres in China. This method of hazard monitoring has found probably most widespread application in this country – a special system of EME monitoring has been developed there (He et al., 2002). The system has already been applied in nearly thirty mines and the EME method of forecasting rockburst is highly valued since it does not require drilling, does not disturb work in the mine, the equipment is easy to operate and the cost of using the method is low. The system, referred to as KBD5, consists of highsensitivity, wide frequency, directional receiving [3].

3. Conclusion

EME from rocks is a promising precursor to predict hazards in the mine. Further research is needed to precisely determine the phenomenon parameters. The measurements performed on rock samples showed EME to be a good precursor for determining the maximum strength of materials and suitable for determining the state of stress of the rock mass. This has been clearly demonstrated by the laboratory tests and fields studies. So far the systems based on AE have been widely used to determine the fall hazard in mines. But the installation of such systems is time-consuming. The systems based on EME require much less time to install.

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