Use of heading-and-winning machine parameter loggers to predict gas-dynamic phenomena at potash mines

D I Shishlyannikov¹, A E Pushkarev²

¹ Perm National Research Polytechnic University, 29 Komsomolsky Avenue, Perm, 614990, Russia
² Saint-Petersburg State University Of Architecture And Civil Engineering, 4 Vtoraya Krasnoarmeiskaya St., Saint Petersburg, 190005, Russia

E-mail: 4varjag@mail.ru

Abstract. The paper presents analysis of the main instrumental monitoring methods of potassium beds outburst hazard. The main disadvantages of the existing means of predicting gas-dynamic phenomena in potassium beds are the low automation level and the cyclicity of measurements at a certain pitch or time interval, which leads to a decrease in the productivity of mechanized combine systems and adversely affects the safety of processes in the shrink stopping. The main requirements are laid down, which shall regulate the development of methods and techniques for predicting gas-dynamic phenomena in potassium beds. Design and operating principle of VATUR software logging system developed by members of the Mining Electrical Engineering Department of the Perm National Research Polytechnic University is described. The results of experimental researches on estimation of size and character of change of energy parameters of a potassium bed fragmentation by operating cutters of Ural-20R heading-and-tunneling machines are presented. The researches have shown that the measurement technique and the equipment reveal deviations of specific power inputs of a potassium bed fragmentation by the machine’s operating members with high accuracy and speed. The results of the experimental studies made it possible to substantiate the prospects of using the energy parameter loggers of cutter-loaders at predicting gas-dynamic phenomena at potassium mines. The suggested concept of the software measuring complex can be used in the development of on-board parameter loggers of the heading-and-winning machines in potassium mines.

1. Introduction

For enterprises mining potassium ore underground using mechanized combine systems, the safety of mining operations at increasing both the winning machine performance and the face output. The successful solution of this challenge is facilitated by the development and active introduction of onboard performance monitoring systems for mining machines, providing for registration and recording of information about the load of the cuter-loader drives, signaling the unacceptable development of events and violation of the potassium ore mining process.

The changes in the stress-strain state (SSS) of the potassium salt bed during intensive cleaning operations cause an increase in the probability of gas-dynamic phenomena (GDP), accompanied by collapses and releases of significant amounts of rock mass into excavations. Dynamic phenomena mainly occur in the face area, threatening the health and life of miners.
2. Research methodology

Nowadays, the main way to prevent GDP at potassium mines in Russia and the CIS countries is the current predication, which provides for the identification of outburst-hazardous areas of the potassium bed by instrumental techniques during preparatory and stopping works. The following current GDP predication methods were tested and applied at the Verkhnekamskoe potassium-magnesium salt deposit.

The barometric GDP predication method in the potassium bed is based on the measurement of the pressure buildup rate and the amount of gas in the boreholes drilled and sealed in the roof rocks. Due to the simplicity of the equipment and measurement techniques, the method has become widespread in potassium mines. However, the insufficient reliability of the barometric method shall be noted, due to the fact that it is based on the GDP manifestation concept due to the action of non-associated gas alone, regardless of SSS and physical and mechanical properties of rocks. Barometric control devices impose strict requirements on the hole mouth diameter, which affects their sealing reliability. However, it is disregarded that if gas is actively drained from the potassium bed, the stress inside the mined formation is relieved, and the outburst hazard is reduced. For the same reason, the potassium bed outburst hazard control method based on the measurement of combustible and toxic gases concentration in the underground environment by installation of onboard stationary gas control equipment, e.g., SD-1 sensors or IKG-9 gas concentration meters on the machine, shall be considered as insufficiently reliable.

The GDP acoustic predication method is based on the dependence between the potassium bed outburst hazard level and the volume of micro-occluded gas localized in salt crystals. The method is implemented by recording the acoustic signal when dissolving salt crystals and releasing gas into the brine. The disadvantages of the described GDP predication method are low reliability caused by the temperature effect and the influence of insoluble residue on the acoustical activity of salts. This method would be reasonable to use in the relative estimation of the micro-occluded gas content in rocks.

GDP predication methods based on the assessment of the mechanical state of saliferous rocks are characterized by high reliability. Outbursts are known to be more likely to occur the closer the rocks around the mine are to critical SSS. Assessment of the strength of saliferous rocks, taking into account their potential energy accumulated from the rock and gas pressure forces shall be carried out by contact method and well drilling with core sampling. The contact method involves pressing a spherical indenter into the walls of wells drilled along the perimeter of the workings, obtaining and analyzing of saliferous rock fracture diagrams. The core sampling method evaluates the nature of fracture and the size of core fragments collected while drilling wells [1].

The main disadvantages of the above methods (except for the method providing for installation of gas control equipment on the machine) are the low automation level and cyclicity of measurements at a certain interval or period of time during which the GDP may occur. In order to obtain reliable information at mines with multiple movable faces significant staff is required, to carry out measurement campaign, frequent transfer and installation of equipment. The use of existing GDP predication tools in close proximity to the face is hampered by the need to conduct the basic potassium ore mining and transportation processes, and may negatively impact the overall performance of the mechanized complex.

Taking into account the above mentioned aspects, the development of the current GDP predication methodology in the potassium bed shall be carried out in accordance with the following requirements:

– comprehensive accounting of all factors influencing the GDP formation (strength and strain parameters of rocks, presence of occluded gas and changes in the rock SSS during mining operations);
– continuous measurements for the purpose of GDP predication;
– measurement campaign should not impede the potassium ore mining and transportation processes.

Potassium bed outburst hazard predication technique suggested by B.V. Laptev and M.M. Bey meets these requirements to the fullest extent (Perm, All-Russia Mineral Salt Production Research and
Development Establishment) [2, 3]. The method is based on the provision that the saliferous rock in the outburst hazard are of the bed is characterized by reduced strength and increased tension due to the presence of rock and gas pressure. The results of numerous researches carried out by the members of the All-Russia Mineral Salt Production Research and Development Establishment allowed establishing the unique dependence of compressive strength, cutting resistance, mineralogical composition and the saliferous rocks outburst hazard. It follows from the above that GDP zones can be predicted through continuous monitoring of specific energy consumption for the potassium bed fragmentation by operating cutters of heading-and-tunneling machines.

3. Research procedure and analysis
The research aimed at to determine the energy parameters of the potassium bed fragmentation process by Ural-20R machines operated at the mines of PJSC Uralkali were carried out by members of the Mining Electrical Engineering Department of the Perm National Research Polytechnic University, in cooperation with experts from LLC RCC (Perm). Figure 1 show that the experimental research methodology provided for the use of VATUR portable logging system, which measures and logs instantaneous currents and voltages of electric motors onboard of the operational heading-and-winning machine [4, 5].

![VATUR software logging system](image)

**Figure 1.** VATUR software logging system: a) general view; b) functional chart; 1 – power supply unit; 2 – processor unit; 3 – switching unit; 4 – current sensors (current clamps); 5, 6 – voltage sensors; 7 – distometer

VATUR complex consists of a processor unit, power supply and switching units, current clamps, voltage sensors and a distometer. The processor unit consists of an industrial computer for portable systems, and an analog-to-digital converter (ADC). The current clamps ensure that the input current is converted into an output voltage of 1A : 1mV. Voltage sensors convert input voltages up to 1000 V into output voltages at 1 V : 3mV. Signals from current clamps and voltage sensors are fed to the ADC input connected to the computer. The distometer is based on an incremental PUF-6 rotary encoder with 360 strokes per revolution. The sensor is mounted on the side skid and ensures that the machine’s movement is recorded.

Within a 20 ms power supply period, 100 measurements take place. Every 0.5 second the effective current, voltage, active and total power values are calculated and recorded to the computer’s hard disk.
Pre-measurements on the machines have shown that the supply voltage and load are symmetrical, so a single wattmeter method has been adopted to measure the active power in a three-phase circuit. Figure 2 show that visualization and processing of the received data is carried out by means of specially developed VATUR-off software. The following graphs show the changes in the active power consumption of the electric motors of the machine’s cutter wheels relative motion; the starting (A-B), idling (B-C), cutting (C-D) and steady state (D-E) areas can be identified.

Figure 2. Graphs of active three-phase electric motor capacities at the average speed of Ural 20R machine – 10.5 meters per hour: 1, 2 – cutter wheel relative movement drives; 3 – breasting device drive; 4 – conveyor drive. Grid line interval – 5 s. Footnotes refer to instantaneous active power values, kW.

The energy parameters of Ural-20R machines were registered by VATUR complex at SKRU-3 mine, Krasnyi-II formation of PJSC Uralkali. The researches were conducted in accordance with the manufacturer-approved technique. The machine was running a continuous face with a conservative feed rate. Single measurement included the machine’s operation at breaking of three to seven ore cars with a given speed of 4 to 12 m/h.

Figure 3 show that the machine’s specific energy consumption depends significantly on the feed rate. Due to insufficient capacity of self-propelled cars, machines operate at reduced feed rate $V_n=6–7$ m/h. Machine’s operation with nominal engine load and performance close to the nameplate load at $V_n≈12$ m/h leads to a 1.5-times reduced energy consumption for mineral extraction.

The researches have shown that the technique and the equipment reveal deviations of specific power inputs of a potassium bed fragmentation by the machine’s operating members with high accuracy and speed. Bed fragmentation-related energy consumption values correlated with the machine’s feed rate can be saved as reference in the memory of the machine’s software logger. Further, during stopping works the reference values are compared with the actual readings and at reduction of specific energy consumption of bed defragmentation by more than 25% the system signals about possible GDP occurrence [6-8].
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Figure 3. Dependence specific energy $H_w$ consumption at potassium bed fragmentation with an epicyclical disk on Ural-20R machine’s feed rate $V_п$

VATUR software logger ensures creation and storage of data sets containing the information on quite long operation periods of the heading-and-winning machine, enables control the operating parameters, determine the technical performance and operating time of the machine. The analysis of wattmetergrams characterize the rhythmicity of mineral extraction processes and its transportation into the shrink stopping enables to estimate the work organization level and the equipment loading level, to reveal negative tendencies and factors influencing the performance of the mechanized complex. In case of emergency, the wattmetergram is a basis to review and identify the causes of the accident and the actions of personnel [9].

The spectral analysis of the current signals received via VATUR software logger, enables to reveal the frequency components from 0 to 100 Hz, characterizing the vibrations of operating device – gearbox – drive motor kinematic chain. Defects in work units and mechanical transmissions cause variable loads, which causes new spectral components. Periodic measurement of values in the current spectrum characterizing specific defects in the drive motor and mechanical transmission, allows assessing the technical condition of the winning machine and, if necessary, carry out repairs aimed at preventing emergency failures [10].

4. Conclusion

Thus, the use of the winning machine performance loggers providing for continuous control of the energy parameters of the potassium bed fragmentation process allows the easiest way to carry out the current GDP predication and identify the outburst hazardous zones in the bottom-hole area, which leads to an increase in the safety of drifting and stoping operations at potassium mines. The suggested concept of the software measuring complex can be used in the development of on-board parameter loggers of the heading-and-winning machines in potassium mines.

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