Geomechanical properties determination based on data obtained from in-seam boreholes logging

Leonid A. Rybalkin[a]*, Anton V. Azarov[a], Andrey V. Patutin[a], Tatyana V. Shilova[a], Sergey V. Serdyukov[a]

[a] *Institute of Mining SB RAS, Novosibirsk, Russia*
* leonid.rybalkin@gmail.com (*corresponding author's E-mail)*

Abstract

To ensure the safety of underground mining, there are different technologies to reduce the risk of sudden rock outbursts. Coal mines are equipped with degasification system and often have a number of boreholes for efficient and effective gas drainage. The development of in-seam directional drilling technology results in an increase in the length of the wells drilled from underground workings. Up-to-date rigs allow drilling more than 1000 meters with a minimum deviation from the desired path. Most often, these wells are immediately connected to the general degasification system and are not used to obtain the unique data from unaffected rock mass.

The aim of the study is to develop techniques and methodical approaches to an evaluation of geomechanical condition and physical properties of a rock mass at a considerable distance from the underground workings. Designed equipment will allow obtaining data on the mechanical stress acting in the massif based on the hydraulic fracturing method as well as gas recovery and temperature depending on the stress state of rocks. This will improve the quality of gas-dynamic activity forecast of methane-bearing coal seams.

As a result, the work provides a new way of logging in long methane drainage boreholes with original automatic delivery system based on the straddle packer assembly.

Distinctive features of the equipment to be developed are: the possibility of complex profile measurements along the borehole, automatic delivery system which does not require the use of expensive directional drilling rigs. Construction of experimental logging tool is scheduled for 2015.

Keywords: In-seam drilling, Rock Properties, Stress State, Forecast, Safety

1. Introduction

Underground coal mines are hazardous production facilities which are potentially harmful for employees. Despite the fact that the solution for preventing unfortunate incidents and for minimizing their consequences has received considerable attention of scientists and engineers, the number of accidents caused by explosions of methane in the current working areas remains unacceptably high. The most destructive and powerful methane explosions occur during longwall mining with high production rate, and these types of accidents have become very common.

Increasing the intensity and depth of underground operation, as well as the complexity of geological and physical conditions and geodynamic environment reduces the time for decision making and correcting the development plan after the discovery of the problem areas within rock massif. This leads to downtime of mining production equipment and reduces the productivity in the coal mining industry.

The lack of information received in advance about stress state and conditions of the rock mass increases the risk of catastrophic events caused by rock pressure, hydro- and gas-dynamic phenomena; especially while development of deep gas-bearing coal seams.

One element of the solution to this problem is to increase the depth and number of methods for rock investigation by performing measurements in the deep in-seam wells which became more and more widespread in the mining industry in developed countries. Another important issue is the development of methods for risk assessment for the reaction of gas-bearing coal seams on the changes of geomechanical condition in the zone that is close to the coal face.

The aim of present study is to develop methodical and technical approaches to the physical and mechanical properties determination at a considerable distance from the underground workings.

2. Application of directional drilling to improve the safety of underground operations

A maximum production rate of coal with modern effective equipment is often limited only by gas factor. To reduce the amount of methane in workings the preliminary methane drainage is used. The growth in drilling of degasification wells in coal mines, including placing boreholes with directional drill rigs, suggests that a lot of attention is paid to safety and efficient use of coal bed methane.

Modern drill rigs (Fig.1) allow controlling the position of bit at 1000 meters and more from the wellhead and driving the well through the desired trajectory; have different size and modular construction that help to reach large volumes of drilling (Hungerford et al., 2013; Karacan, 2013).

1 *2*

Fig. 1. Directional in-seam drill rigs: *1* – VLD 1000A (Australia), *2* – ZDY 4000 LD (China).

The experience in the development of gas-bearing coal seams in China and Australia shows the effectiveness of degasification procedures based on a large volume of directional in-seam drilling. The borehole layout is designed according to specific mine characteristics and basic parameters measured in the coal seam, such as gas contents, gas pressure and effective radius of boreholes for gas drainage. Reservoir simulation techniques may be used to determine boreholes spacing and degasification time requirements for specific geological conditions. Fig.2 illustrates the in-situ gas content reduction achieved by 500 m in-seam borehole in a low permeability coal seam after two years (Brunner et al., 1999).

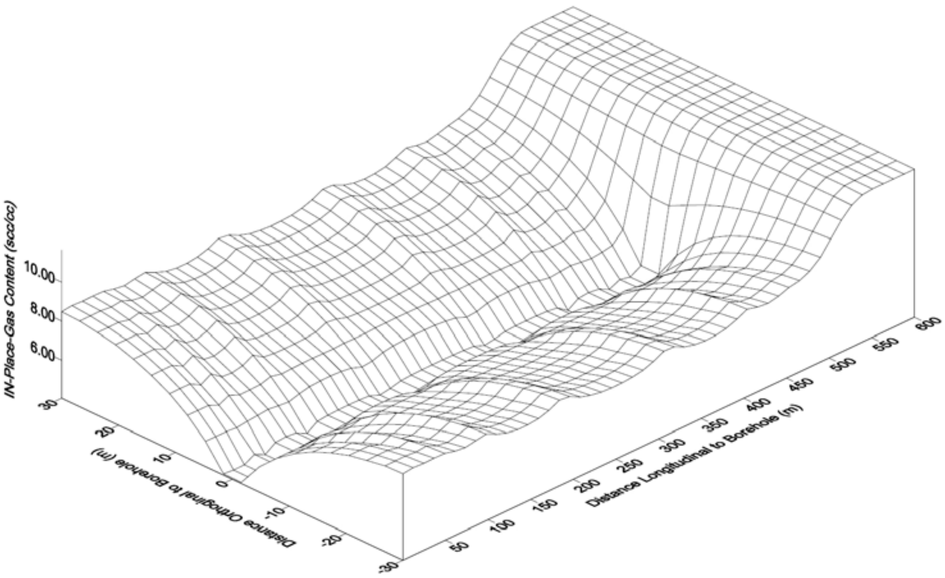

Fig. 2. In-situ gas content achieved with 500 m in-seam well in a low permeability coal seam.

For efficient gas drainage should be considered the following: geological features of the work area, geomechanical and filtration properties of coal seam, gas content and others. One of the main causes of untimely outburst prediction and inaccurate estimates of methane volume in the mine workings and in drainage boreholes is the lack of reliable logging systems for these types of wells. Such studies are required to optimize the boreholes layout and technological schemes of preliminary degasification, to assess the risk of gas-dynamic phenomena and rock pressure, to search for prospective sites for the exploration of coal bed methane, to predict outbursts in advance of workings.

Despite the large in-seam drilling practice in main coal producing countries, there is little experience regarding geophysical prospecting and well testing in long boreholes drilled from underground. Often the information about coal seam and its boundaries is obtained through gamma logging while drilling. Conducting well logging operations is complicated by specific recording conditions: boreholes often do not contain the mud used in traditional oil and gas industry; downhole tools require additional calibrations, as there are significant differences in the physical properties of coal and petroleum rocks; equipment should be certified as intrinsically safe (IS) for underground use. Another issue that in-seam boreholes are immediately connected to the general degasification system and are not used to obtain the unique data from unaffected rock mass.

3. Automatic delivery system for in-seam boreholes

The main feature of the in-seam drilling technology is the presence of horizontal sections of considerable length. As a rule, any horizontal borehole is complicated by falling and raising intervals. In this regard, delivery of equipment is a complex and actual problem for the organization of geophysical survey. The next step for improving the quality of in-seam research is the creation of instrumental base and technologies allows continuous monitoring and recording of downhole parameters in different intervals of the horizontal well. To meet these challenges, the proposed technology should ensure that the following requirements: possibility of conveying devices along the entire length of the borehole and installing them at any given interval and possibility of long-term logging with measurements at different loading modes.

The following methods are used for transportation and delivery borehole tools along the entire length of the in-seam well:

a) coiled tubing technology (Meyer et al., 2007);
b) fluid or gas pressure for pushing device along the well;
d) rigid logging cable delivery;
e) delivery via automotive robotic devices or downhole tractors (Fig.3).

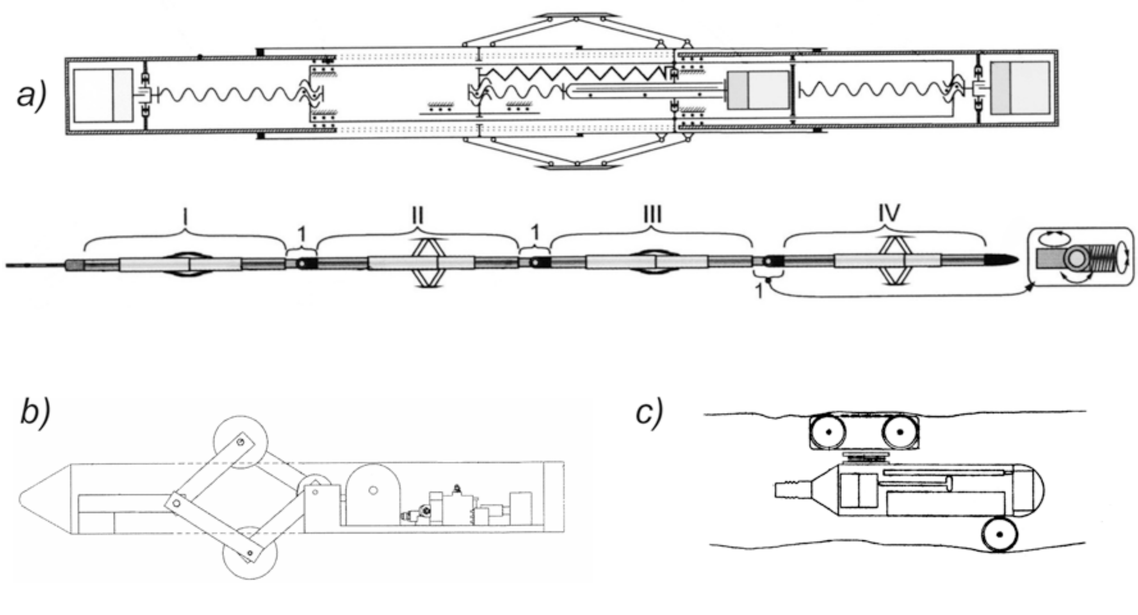

Fig. 3. Advanced delivery systems for borehole equipment: *a)* tool for delivering tools into open hole horizontal section, where I, II, III, IV – anchoring sections, *1* – moving module (Patent RU 2515141); *b)* downhole tractor with wedging supports (Patent RU 2487230); *c)* downhole tractor with two different types of wheel sections (Patent US 6845819).

Modern research facilities used in mines oriented mainly to measurements at small (up to several meters) distances from the workings and implement no more than one or two methods that do not fully meet requirements of underground mining of coal-bearing seams. Known systems are focused on the delivery by drilling rods, and it is unacceptable in the case of directional drilling because of the high cost of the inappropriate use of expensive equipment.

Based on the analysis of known solutions the original idea of combining an automatic delivery system and straddle packer assembly for interval hydraulic fracturing is suggested. The developed arrangement allows to carry out following operations:

a) stimulation of gas drainage from coal seams;

b) creating impermeable screens in the rock mass to avoid gas and water filtration;

c) stress state estimation in a given interval of the well.

Although hydraulic fracturing method is widely used for different types of gas reservoirs including low permeability rocks, there should be some adjustments to the process because of the following properties of the coal: extensive natural network of fractures that cause different unexpected features such as fluid loss, borehole instability and others; surface of the coal absorbs chemicals of the fracturing fluid; high pressures are required to fracture coal (Halliburton, 2007).

It is necessary to consider formation properties and the state of methane in the coal bed to make hydraulic fracturing successful. As a rule, coal seam has high water saturation, low effective permeability, as well as a low reservoir pressure. Laboratory studies show that the majority of gas adsorbed by coal (Mavko et al., 1986). Therefore to maintain high gas production and desorption it is required to pump out the water first and relieve the stress on the reservoir. Water can also significantly reduce the permeability of coal to methane and block its filtration to drainage boreholes, which increases the time for the degassing.

Another negative factor encountered during the operation of drainage is a low content of methane in the pumped gas, and often the reason is the poor quality of borehole sealing. Impermeable screen provides the decrease in air flow that goes from the opening to the borehole through the small channels and cracks induced by in-seam drilling.

The process of creating the barrier with special compounds consists of three major steps. With the straddle packer system transverse fracturing in certain interval of the well is performed. The fracturing fluid is selected based on its ability to avoid the leakage of the liquid filler pumped into the shield on the next step. The liquid filler is heated, and has low viscosity in order to fill all fracture volume. While cooling the viscosity decreases and opened fracture that blocks the air filtering through it is formed. At the third stage, the polymer sealant is applied with a rapid solidification rate which prevents the fluid output from the screen.

Experiments have shown that the compounds used are providing significant reduction in gas permeability at a pressure that is not lower than the pressure of the axial compression observed in the fracture (Shilova et al., 2013; Kurlenya et al., 2014). This working pressure is sufficient to open the fracture, to fill it with special fluid and create the impermeable barrier. This technology can be used with developed equipment and will increase the quality of pumped gas.

Another application of the hydraulic fracturing is the stress state evaluation. A short segment of the borehole is sealed off with straddle packer assembly. Then working fluid is pumped into the fracturing interval until the rock mass fails in tension at a recorded pressure. The main parameter that is used in different calculation schemes is the shut-in pressure – the lowest fracturing interval pressure at which created fracture closes completely under the action of the stress acting normal to the fracturing plane.

Additional modules are developed for gas flow and temperature logging that can be used within the transport device. Measurement of these parameters can be carried out during packer’s inflation and its acting to the borehole walls causing the local stress field to change.

Briefly scheme of moving is shown in Figure 4.

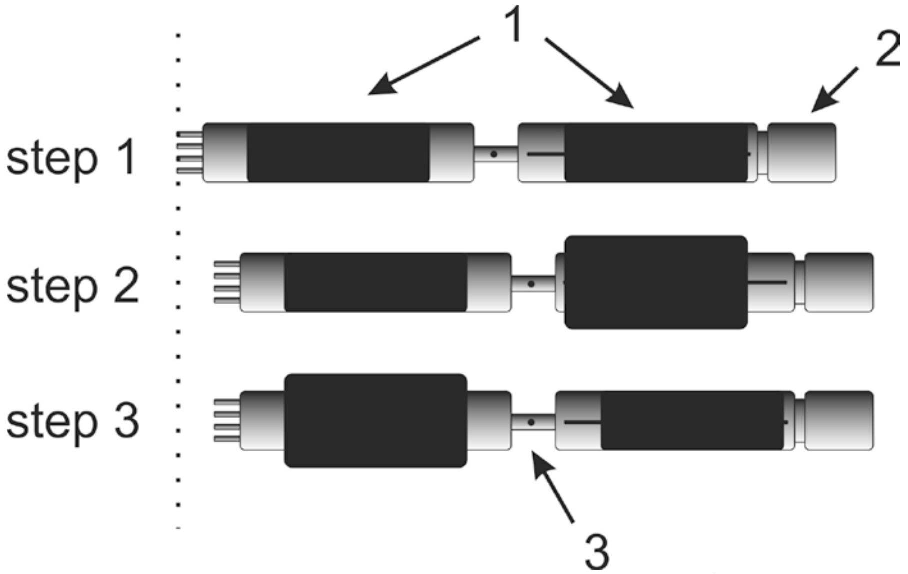

Fig. 4. Delivery system based on reciprocating motion: *1* – inflatable packers; *2* – hydraulic cylinder; *3* – fracturing interval.

In the first step the device is placed into the well; both packers are deflated. Before moving the pressure is fed into the packer that is close to the hydraulic cylinder, which leads to its being firmly anchored to the borehole wall. In the second step, the hydraulic cylinder starts operating and there is a pulling the entire device relative to the anchored packer take place. After that, another packer is inflated and packer that was anchored is deflated. Special spring pulls deflated packer to the hydraulic cylinder (step 3). After dropping the pressure in both packers device completes one cycle of motion and a new cycle begins. Distance from the wellhead is controlled by the length of high pressure hoses connected to the device.

Profile measurements of physical properties of rocks as well as its fracturing, can be performed by pulling the device out of the borehole or reverse mode operation. Logging or fluid impact are carried out at given points as often as necessary.

The relatively small physical dimensions of the device will permit the operation of directional hydrofrac in deviated wells; and the use of one meter packer sleeves will significantly improve the quality of the fracture interval sealing and eliminate bypassing the packers by cracks. The formation of transverse fractures is assumed due to the short length of the fracture interval which is less than the double diameter of the borehole; and built-in mechanical plunger for crack growth initiation will provide fracture propagation in the plane normal to the borehole axis.

4. Conclusions

The new approach to the in-seam boreholes logging was suggested. Known methods and technical solutions for the equipment delivery were analyzed and automatic system combined with measurement modules is offered. One of the distinctive features of the developed equipment based on straddle packer assembly is the possibility of its independent movement along the borehole without help of the expensive directional drilling rig.

In addition to physical properties logging, the developed equipment allows to carry out three different operations using hydraulic fracturing method: stimulation of gas drainage from coal seams, creating impermeable screens in the rock mass to avoid gas and water filtration and stress state estimation in a given interval of the well. These tasks are solved by the crack propagation occurs in the plane that is orthogonal to the borehole axis.

At the next stage of the research laboratory experiments and field tests will be performed.

Acknowledgements

This work was made in Institute of Mining, Siberian branch, Russian Academy of Science and supported by Ministry of Education and Science of the Russian Federation, Project RFMEFI60414X0096.

References

Brunner, D., Schwoebel, J., 1999, Directional drilling for methane drainage and exploration in advance of mining, *REI Drilling Directional Underground, World Coal*, 10 p.

Halliburton, 2007, Coalbed Methane: Principles and Practices, 420 p.

Hungerford, F., Ren, T., Aziz, N., 2013, Evolution and application of in-seam drilling for gas drainage, *Int J Min Sci Technol.*, 23, 543-553.

Karacan, C., 2013, Integration of vertical and in-seam horizontal well production analyses with stochastic geostatistical algorithms to estimate pre-mining methane drainage efficiency from coal seams: Blue Creek seam, Alabama, *Int. J. of Coal Geol.*, 114, 96-113.

Kurlenya, M., Shilova, T., Serdyukov, S. and Patutin, A., 2014, Sealing of coal bed methane drainage holes by barrier screening method, *J. Min. Sci.*, 50 (4), 814-818.

Mavko, B., Hanson, M., Nielsen P., and Logan T., 1986, Hydraulic fracture model for application to coal seams // *Proc. of the 27th U.S. Symposium on Rock Mechanics (USRMS)*, Paper ARMA-86-0741.

Meyer, T, Lugg, P and Black, D., 2007, Coiled tubing drilling system development – risk mitigation, *Australian Coal Association Research Program*, Project C27132.

Shilova, T., Patutin, A., Serdyukov, S., 2013, Sealing quality increasing of coal seam gas drainage wells by barrier screening method, *Proc. of 13th SGEM GeoConference on Science and Technologies In Geology, Exploration and Mining*, 1, 701-708.