Ensuring stability of maintained goaf by means of directional hydraulic fracturing (DHF)

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Abstract. The article describes how directional hydraulic fracturing (DHF) of roof rock was used while the longwall face was operating and airway for the isolated methane-air mixture drainage from the goaf was preserved. The authors give the reasons for using DHF in mining and geological conditions of Esaulskaya mine. They describe the sequence of the performed operations aimed at weakening roof rocks and also list the special equipment used during the process. Based on the results of the performed operations, the authors make a conclusion concerning the effectiveness of this work.

1. Introduction

Industrial experimental work aimed at implementation of directional hydraulic fracturing of roof in different process flows is taking place in Kuzbass [1, 2].

Longwall face 26-25bis in Esaulskaya mine has been extracted under extremely complex conditions, namely in the pillar between previously extracted pillars 26-23 and 26-25. The sizes of the protective pillars of airway and belt road do not exceed 6.0 m. Mining-and-geological and mining-and-technical parameters of the working area 26-25bis are given in table 1.

The main roof is represented by fine grain and coarse grain siltstone with thin interbeds of sandstone. The change of main roof types in controlled by the change of lithologic types combinations. In the second part of the longwall face coarse grain siltstone prevailed. This shows that the main roof is formed by the tight rock. Hardness factor according to Prof. Protodiakonov scale for fine grain siltstone equals 6, for coarse grain siltstone it is 7, for sandstone – 9. Estimated spacing of the initial main roof caving is 109.0 m and the secondary – 35.0 m.

Thus, the presence of extremely complex mining and geological conditions of extraction indicated the possibility of sufficient roof hanging when the longwall face is working which leads to excessive loads on props, reinforcement of the preserved part of airway with the possibility to create critical stress on the marginal part of the working. To reduce the negative effect of the excessive pressure of the roof tight rock, the specialists decided to use directional hydraulic fracturing [3, 4, 5].

According to the project documents, ventilation of mine workings during coal extraction from longwall face 26-25bis was performed using combined ventilation circuit with isolated methane-air mixture drainage from the goaf along the maintained part of airway 26-25bis and workings of gas drainage system. The width of protective pillars was 6 m. The main goal during the extraction of longwall face 26-25bis deposits was to preserve a part of the airway 26-25bis for isolated methane-air mixture drainage from the goaf after the longwall face advance.
Table 1. Mining-and-geological and mining-and-technical parameters of the working area 26-25bis.

| Parameter                        | UM    | Value   |
|----------------------------------|-------|---------|
| Longwall face index              |       | 26-25bis|
| Seam                             | 26a   |         |
| Coal grade                       | G     |         |
| Operating ash content            | %     | 30.7    |
| Mining depth                     | m     | 520-550 |
| Seam thickness                   | m     | 1.85-1.92|
| Extraction height                | m     | 2.15    |
| The angle of incidence of the reservoir, from-to, degree | 0-2 |
| - along the longwall face        |       |         |
| - along the extraction column    |       | 1-8     |
| Length of working area           | m     | 1140    |
| Length of working face           | m     | 120     |

2. Results and discussion

The specialists of Institute of Coal of FIC UUKh SB RAS and mine technical workers offered a technical plan to perform a directional hydraulic fracturing of the roof to reduce the strength of rock pressure in the preserved part of the airway 26-25bis in the langwall face 26-25bis (figure 1), which made it possible to “cut” of the roofing bracket over the airway 26-25bis behind the langwall face and save the airway during column extraction in langwall face 26-25bis [6, 7].
Figure 1. DHF engineering diagram: a) boreholes layout necessary for DHF implementation; b) vertical scheme of holes layout for DHF implementation in airway 26-25bis (crosscut A-A).

The engineering procedures involved in performing DHF were established using both standard general use equipment and special one. The boreholes and initiating crevices were made with pneumatic drilling roof bolt setter. Rock boring bits (46 mm in diameter) were used for drilling. Initiating crevices were made with mechanical crevice initiating devices (figure 2), which were fixed on the steel stems of the drill instead of boring bit [8].

Figure 2. Crevice initiating device SHCHM – 45/1.

Sealing of initiating crevice zone was performed by means of hydraulic sealer “Taurus” type (figure 3). Special set of high-pressure pipes was used to deliver sealing agent to the borehole bottom. Compression unit was connected with the pipe ends sticking from the borehole through special adapter (collector) by means of high-pressure flexible hoses. Fluid was forced into the initiating crevice zone by means of high-pressure unit of mechanical complex.
Control over the drilling effectiveness and DHF process was performed by means of video endoscope. As a result of these measures it was found out that the boreholes were drilled on the project depth and there is an initiating crevice in each borehole opening (figure 4).

First of all, DHF is implemented in vertical boreholes when artificial crevices spread along the formation and then in the slant holes when the crevices develop at an angle to the formation. The artificial crevice will come into contact between the main roof and immediate mine roof and further spread along the contacting part (figure 5). When the liquid is pumped into the borehole, the DHF starts 5-10 sec after the emulsion is supplied into the system. There is sharp pressure drop on manometer near the initiating crevice.

![Figure 3. Sealer “Taurus”](image)

![Figure 4. Borehole with initiating crevice before DHY](image)

(a) (b) (c)

Figure 4. Borehole with initiating crevice before DHY (a – video endoscope, b – hole collar, c – borehole bottom).
The authors suggested to use not only visual inspection to monitor the state of DHF parameters through rupture boreholes, but also seismic acoustic rapid test for danger detection. To do that, they installed structure-born noise sensors manufactured by “MarcoGmbH” on supports No.29 and No.31. They were used for data collection and further analysis of seismic acoustic impulses coming from the rock mass. Structure-born noise (vibration) sensors for using in mines have holding magnets which help fix them on any metal surfaces. The sensor detects the frequencies within the range 2.5 – 25000 Hz (period resonance ~50 kHz) [9]. The sensors were placed in fixation hole where the roof beam is fixed to the front row of hydraulic props (figure 6).

System operation principles: structure-born noise sensor detects audible and inaudible sounds (infrasonic vibrations), coming off the rock mass or the part of longwall located near the face. Impulses are registered according to the set parameters. Then the data is transmitted to the data collection gauge, which has a plug-in microSD card. After that the impulses are analyzed by means of special software. Frequency seismic record appears and then data is selected. Depending on the type of contact between the roof beam and roofing, the signal coming from sensor №1 (red) and sensor №2 (green) (figure 7) can have different impulses.

**Figure 5.** 3-D model of DHF planes formation for underground pressure control.
Figure 6. Structure-born noise sensors placement in the roof support.

Received audible and inaudible impulses (infrasonic vibrations) also show that conveyor belt in the longwall and extracting machine are working. This will be seismic acoustic activity rapid analysis of audible impulses only. It is necessary to consider only peak readings of the structure-born noise sensor.

As a result of that work, the authors got a seismic record with audible and inaudible impulses (figure 7). Arrows show the audible impulses.

Figure 7. Seismic impulses.
The seismic acoustic rapid danger analysis method allowed to determine the main criteria for rock pressure dynamic displays. Two main criteria were determined for the given conditions, namely quantity and accumulation of impulses within some time period. While using impulse accumulation criterion it was found out that the accumulation process takes place with deceleration, which indicates safe state of the rock mass.

3. Conclusion
Thus the DHF scheme used for roof rock rupture to form short roof bracket after the advancement of the longwall face as a part of the sequence of measures developed to extract coal deposits in extremely complex mining and geological conditions let reduce pressure on props of the reinforcement of the preserved airway part. This guaranteed necessary (according to the calculations) methane-air mixture volume drainage during the extraction of the whole extraction column (figure 8).

![Figure 8. The state of the preserved part of the airway 26-25bis.](image)

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References
[1] Klishin V I 2002 Adjustment of Powered Roof Support to Dynamic Loading Conditions (Novosibirsk: Nauka) p 200
[2] Klishin V I, Nikolsky A M, Golubev Yu G, Neverov A A and Neverov SA 2008 Trade Magazine “Siberian Coal in XXI Century” (Kemerovo) 7(11) 40–1
[3] Klishin V I, Lakontsev Yu M, Sazhin P V, Klishin S V and Nikolsky A M 2008 Proc. Sci. Conf. on Fundamental Challenges of Technogenic Geologic Environment Formation (Novosibirsk: Coal Mining Institute of SB RAS) pp 123–7
[4] Klishin V I, Buchatsky V M and Konovalov L M 2007 Ugol 6 40–3
[5] Klishin V I, Nikolsky A M, Opruk G Yu, Neverov A A and Neverov S A 2008 Ugol 11 12–7
[6] Klishin V I, Opruk G Yu, Senturev A V and Nikolaev A V 2015 Ugol 11 12–6
[7] Instruction on the Choice of the Parameters and Methods of Roof Weakening in the Extraction area 1991 (Russian Research Institute of Mining Geomechanics and Survey) p 102
[8] Kurlenia M V, Klishin V I and Kokoulin D I 2013 Crevice initiating device Patent RF No 129148 Bulletin 17
[9] Klishin V I, Opruk G Yu and Vessel A O 2016 Science Intensive Technologies in Mineral Resources Extraction and Usage 3 27–33