Boosting the efficiency of hydrodynamic impact on a coal-rock massif employing the method of seismic tomography to control massif’s parameter

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Abstract. The results of numerical modeling of a fracture system spatial development on a coal-rock massif under the hydrodynamic impact are presented. To set boundary conditions, an array of geophysical data obtained with a seismic survey method for the extraction panel roof was used. The parameters of typical geophones placement schemes in mine workings, sufficient for assessing the efficiency of directional hydraulic fracturing are substantiated. Satisfactory convergence of the results of numerical modeling of fracture systems spatial development with areas possessing different physical and mechanical properties revealed during seismic survey of the extraction panel impacted by hydraulic fracturing are presented.

1. Introduction
During a long wall mining in conditions of solid hard-to-cave rocks in the coal seam roofing area, the main roof rocks may hang over the gob area. Subsequently, this can lead to a decrease in mine workings stability, as well as to manifestation of outcrops and falls of the immediate roof strata during the shearsers operation, which significantly reduces the productivity of mining equipment. An effective way to eliminate the negative impact of a hard-to-cave roof on the coal mining process is the roof strata softening by employing a directional hydraulic fracturing (DHF) method, that leads to modification of roof strata geomechanical conditions when artificial cracks advent [1].

2. Mining measuring for controlling hydraulic influence parameters
Based on actual experience of hydraulic fracturing application in a coal-rock massif it is known that the correspondence between the actual and planned directions of crack development is determined by technological factors and physical and mechanical properties of rocks [2].

At the same time, the natural fracturing has the greatest influence on the effectiveness of the hydrodynamic impact [3], which determines its radius $R$ and the dependent location of hydraulic fracturing boreholes in the coal seam. Typically, the distance $R_F$ between the DHF borehole does not exceed 30 m and is determined empirically or analytically based on the use of geological data. However, in the general case, the completeness of these data is limited by the information obtained during delineation of mine workings and with the help of exploration wells entering the extraction panel body, the number of which, as a rule, is very limited [4-5].

To improve the hydraulic fracturing efficiency it is proposed to control $R_F$ with the method of seismic tomography based on passing waves, which involves the registration of passing elastic waves artificially generated by a mechanical source of vibrations with a fixed step from the mine working.
flank by means of autonomous seismic receivers network linearly distributed along the flank of the opposite mine working (figure 1) [6-7].

![Figure 1. Flow diagram of seismic survey between mine workings.](image)

Seismic monitoring makes it possible to assess rock mass stress conditions before and after the directional hydraulic fracturing in a hard-to-cave roof zone. This estimate is based on the dependence of the wave propagation velocity in the massif on physical and mechanical properties changes of various geological formations.

Accordingly, the interpretation of velocity characteristics of the seismic and tomographic cut makes it possible to establish the presence of contrasting regions characterized by changes in geomechanical parameters of the roof [8, 9]. To assess the instantaneous velocities at different sections of the extraction panel under study, analytical approaches were used for tomographic examination of the active roof of a coal seam contoured by two workings (figure 2) using general dependence [10]

\[ t = \int_{S}^{Pr} \frac{1}{V} \cdot dl, \]  

where \( t \) and \( V \) – seismic wave propagation time and velocity; \( l \) – distance from source \( S \) to receiver \( Pr \).

This dependence, when dividing the studied area into \( N \) pixels, takes the following form

\[ t_i = \sum_{j=1}^{N} \frac{1}{V_j} d_{ij} \quad (i=1...n), \]  

where \( n \) – number of observation;
\( d_{ij} \) – distance traveled by ray \( i \) in pixel \( j \).

In experimental studies carried out on the basis of a seismic tomography method, it was found that directional hydraulic fracturing of the roof affects the field parameters of seismic waves passing through the controlled massif and causes a decrease in the general background of velocities. It was also found that active roof state assessment conducted prior to hydraulic fracturing makes it possible to identify, within the study area, zones of propagation and redistribution of high stresses (maximum speeds) and fractured weakened zones (minimum speeds) (figure 3). Together with the available actual data obtained during mine workings delineation, this makes it possible to predict the active roof rocks conditions in the body of the extraction panel [11, 12].
Figure 2. An example of registration by a system of 12 autonomous recorders the seismic waves, propagating in the extraction panel body from the 4th picket of vibration excitation: (a) wave propagation scheme; (b) seismogram.

Figure 3. Distribution of velocity characteristics in the extraction panel area on a seismo tomographic cut.
At the same time, in order to increase the estimate reliability of DHF technological schemes parameters based on geological and geophysical data use, it is necessary to develop model concepts about processes occurring during roof mining (unloading).

3. Numerical modelling of the processes which accompany coal roof loading relief (unloading)
To describe the fracture system formation and development as a result of hydraulic impact on the rock mass, a numerical model has been developed that describes the change in the pore-fracture space volume during the coal rock mass mining.

$$\frac{\partial}{\partial t} (\rho \varepsilon) + \nabla \cdot (\rho u) = Q_m,$$

where $u = -\frac{k_{wp}}{\mu} (\nabla p + \rho g \nabla D)$, $p$ – pressure, (Pa); $k_{wp}$ –permeability (mD); $\rho$ – rock density (m$^3$/kg); $\mu$ – fluid viscosity (Pa·s); $\nabla D$ – unit vector in the direction of gravity; $g$ – acceleration of gravity (m/s$^2$).

Under the given boundary conditions for the hydraulic fracturing fluid flow through the rock mass, straight across to normal phase boundary, the following is true

$$n \cdot \rho \frac{k_{wp}}{\mu} (\nabla p + \rho g \nabla D) = \rho U_0,$$

where $U_0$ – initial value of speed according to Darcy’s law (m/s), $n$ – vector to the normal under given conditions.

According to the results of seismic scanning prior to hydraulic fracturing (figure 4, a), for the numerical modeling of the fracture formation process, regions “A” and “B” were identified, differing in the physical and mechanical properties of rocks, presumably, ensuring the fluid filtration. In addition, contrasting zones were identified on the seismotomographic section: an extended zone of maximum seismic velocities “+" (up to 3.6 km/s), which is characterized by increased strength of rocks, and a small zone of minimum seismic velocities “-" (up to 2.7 km/s) in a fractured weakened state.
Figure 4. Setting basic geological conditions for hydraulic fracturing: (a) seismotomographic section of velocity characteristics distribution in the area of the extraction panel before hydraulic fracturing; (b) setting boundaries for the study areas A and B and predicted development direction of the fracture formed during hydraulic fracturing.

The fracture formation process in a rock mass modeling was carried out in the Comsol Multiphysics environment under the assumption that fluid at high pressure enters the rock mass through a borehole interval sealed with a packer, followed by the fracture development in the rock mass in zones “A” and “B”. Graphical plotting of the fracture (figure 4, b) is performed in an interactive mode. Further, at the boundary “fracture bank - rock”, the initial conditions of fluid filtration through fractured rocks were set and in numerical experiments the spatial distribution of fluid pressure in the rock mass was obtained with a developed fractures system during hydraulic fracturing (figure 5, a), which allows predicting the progress in extraction panel roof mining.
Figure 5. Matching the results of numerical modeling with geophysical data: a) modeling results of fluid pressure distribution in the rock mass with a fracture developed during hydraulic fracturing; b) seismotomographic cut of the investigated roof area, obtained after hydraulic fracturing.

The numerical modeling results of the fracture system spatial development fit well with the location of areas differing in physical and mechanical characteristics, revealed during extraction panel seismic scanning implemented after hydraulic fracturing (figure 5, b). This is reflected in the development of the previously registered zone of minimum seismic velocities “-” within the mine working 2 and the formation of a similar zone within the working 1, as well as in a significant area reduction of a maximum seismic velocities zone “+”.

4. Conclusion

Thus, the fundamental possibility of using seismic information results interpretation in the process of DHF scheme parameters calculation has been substantiated. Within the received views progress, it is planned to carry out experimental work on hydraulic fracturing, and ensuring its parameters control based on seismic scanning data.

Acknowledgements

The study was supported by the Russian Science Foundation grant (project No. 17-17-01143).

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