Investigation of coal discharge modes on brassboards of powered roof support unit

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Abstract. Physical and analytical modeling of caved top coal discharge by adjustable feeders on armored face conveyor during underground mining of thick flat seams has been performed. The process of top coal caving is studied using laboratory installation with the feeders operating in wave and areal modes. Based on 3D discrete element method (DEM), gravity flow of coal and its interaction with the powered roof support unit is modeled numerically.

1. Introduction

In the world practice, there are to prevailing technologies for thick flat coal seams: slicing and full-height cutting with top coal caving. Longwall slicing features high loss of coal and endogenous fire hazard. Therefore, the second-listed technology is more preferable.

Advantages of LTCC technology are described below:
—coal is extracted full-out, which contributes to high concentration of mining and reduction in coal loss and endogenous fire risk;
—development heading, as well as the cost of construction and support is reduced 1.5–2 times;
—the force of rock pressure and the effect of top coal self-caving are utilized, which lowers energy expenditure of coal mining;
—expenses of longwalling equipment and face haulage machines are cut down;
—expenditures connected with assembly and disassembly of transportation facilities, electric equipment, pipelines as well as precautions, etc. are lowered;
—coal production cost is reduced as output per face jumps at a comparatively minor increase in the number of longwall personnel.

There two variants of LTCC: with coal discharge to the front or rear-mounted armored face conveyor. In the first variant, the discharge opening is located nearby the face, which allows shorter roof support units but top coal is in this case underprepared for self-caving due to small distance from the roof to the canopy. For this reason, even in soft coal, it is required to undertake additional loosening. Furthermore, insufficient coal discharge is accompanied by considerable dusting, which elevates operation riskiness. In the second variant, the conditions of coal discharge to rear-mounted AFC are favorable for deformation and fracture of top coal. On the other hand, it is required to increase dimension of the roof support units and to mount the rear AFC available. Thus, the structure of roof support is complicated and it is necessary to include a rehandling facility at the longwall-and-conveyor drift junction, which creates additional maintenance difficulties [1–4].
These technological variants have a common drawback—the caved coal flow size is limited and, thus, the loss and ash content of coal increase, especially in coarse-size flow. These shortcomings can be eliminated with coal discharge along the whole length of longwall, from all support units simultaneously. In this case, the coal and rock interface caves in concurrently, which allows an area-controllable discharge [5].

Rock flow is adjusted by means of forced–controlled discharging by feeders included in the support units. For implementation of these technologies, the optimized approach to treatment of top coal to ensure physical possibility of coal discharge have earlier been justified: vibro-seismic treatment and multi-stage hydraulic fracturing.

The proposed structure of powered roof support with adjustable coal discharge to AFC is designed with regard to geomechanical behavior of coal and roof rocks, embraces advantages and eliminates disadvantages of the known designs (Figure 1).

Inclusion of feeders for discharge and loading of caved top coal in the structure of powered roof support is a new trend in creation of high-productive technologies in the coal mining industry. In this regard, it is of the current concern to undertake both fundament and applied research into laws and consistent patterns governing rational parameters of powered roof supports with forced-controllable coal discharge.

Figure 1. General view of powered roof support unit with adjustable flow of caved top coal to AFC.

2. Laboratory experiment
The main approach to study laws of flow is observation and recording of flowing mass simulating coal with interbeds. For the investigation of controlled caved top coal discharge to AFC during thick coal mining, a laboratory installation [6, 7] as well as the lab test program and procedure [8] were developed.

The lab-test installation allows simulating the process of thick coal cutting with top coal caving and discharge to face area. The body of the installation is a box structure with transparent sides and bottoms made of organic glass 10 mm thick. The transparent walls of the box enable visual observation of flow behavior.

Twenty brassboard units of roof support with relocating devices are placed in the box until their shielding touches the back wall of the box. The brassboard units are made at a scale of 1 : 25 relative to the full-size unit of a powered roof support. Total width of the brassboard unit equals the inner thickness of the transparent box (1600 mm).

Coal flow is simulated by black painted gravel fraction 5–15 mm; dirt is modeled by grey-pinky marble chips 13–25 mm in size. For visualization, the coal-simulating material is parted by a layer of white gravel fraction 5–10 mm (Figure 2a).
The discharge control system is instrumentation and software capable to measure characteristics of feeder (frequency, amplitude) and operating modes (individual, grouped). The installation is equipped with photo and video recording tools.

The investigations were carried for geological conditions as follows: coal seam thickness—7.5 m; active roof thickness—4 m; cutting layer thickness—3.5 m; top coal thickness—4 m.

Coal was discharged by sequentially actuated feeders on the 1st to the 8th units with their velocity decreasing in the same sequence. When the coal–rock interface approached the discharge openings of the 1st and 2nd units (Figure 2a), these feeders were deactivated and the feeders of the 9th and 10th units were switched on. Then, the units were advanced. The advance step was 32 mm, which corresponded to the advance of the real unit of powered roof support for 0.8 m. After three advances, the discharge process was restarted. All in all, three advances and discharges were performed. Total length of advance made 5.6 m (in real scale terms). The final stage of the laboratory experiment is demonstrated in Figure 2b.

**Figure 2.** Wavy discharge flow: (a) initial stage; (b) final stage.

The feeders were actuated sequentially, with the velocity decrease toward the 10th unit. That was the wavy mode of discharge flow. From the 11th to 20th unit, we observed the full-length flow, with all feeders operating simultaneously and at the same velocity (Figure 3).

**Figure 3.** Full-length discharge: (a) initial stage; (b) final stage.

Alongside the wavy and full-length flows, the laboratory experimentation procedure provided individual (by each unit one-by-one) and grouped (by a group of 3–5 units simultaneously) modes of discharge.

3. **Discrete element method-based modeling**

Together with lab tests of controllable coal discharge, numerical modeling of gravity flow of precrushed rocks was carried out in order to find consistent patterns in interaction between the powered roof support
units and the discharge material flow. The 3D modeling used the discrete element method. In a space \( Oxyz \) a domain was set as a parallelepiped bounded by planes directed along the coordinate axes. The length and width of a box filled with granular material are 10 and 2 m, respectively. The fill height is 12.5 m (Figure 4a). The gravity vector is directed along the axis \( Oz \) vertically downward. The coal seam thickness is 7.5 m, the powered roof support units, 3D modeled in Figure 4b, is 3.5 m high.

![Figure 4. (a) Crushed rock discharge; (b) 3D model of powered roof support unit with gravity discharge.](image)

The selected physical parameters of coal and dirt particles (elasticity modulus, Poisson’s ratio, density) are typical of coal deposits in Kuzbass. The calculation of forces at the particle contacts took into account dry friction, rolling resistance and viscosity.

The domain was filled with discrete elements using a dynamic algorithm imitating movement of particles under the action of a pre-set external force (gravity). In order to reach maximum density of the packing, friction between the particles and between the particles and the box walls was withdrawn from that stage of modeling. Finally, the equilibrium packing of granular material was represented by a population of discrete elements with total mass of coal particles—58 t and dirt—195 t. Then, the angles of the contact sliding friction, \( \varphi_{ij} = 30^\circ \), rolling resistance, \( \psi_{ij} = 30^\circ \), between the particles were fixed. When the crushed rock mass reached equilibrium, the discharge opening was opened, and the material started moving until the next state of equilibrium. The latter was ensured by the immobile flow gate and switched-off feeder. Later on, the feeder was set in reciprocating motion (full travel 0.3 m, vibration period 2 s). Owing to friction at the contacts between the particles and feeder, the material was dragged in motion. The crushed material flow became steady-state in some time. The total flow rate of coal in that mode of discharge for 45 s of testing made on average 32 kg/s; the total mass of discharged coal was 1500 kg.

4. Conclusions

As a result of the laboratory simulation and numerical modeling, it has been found that the design of the powered roof support with discharge openings equipped with adjustable capacity feeders enables metered flow of caved top coal to AFC. As a consequence, this allows coal discharging through opening in a number of the support units simultaneously, which provides full-length or wavy discharge, which prevents coal dilution and minimizes losses.

The presented DEM-based model of gravity flow of fragmented rocks in coal mining by the longwall top coal caving technology takes into account basic stages of the process: creation of initial
equilibrium state of rick mass; discharge of coal to the feeder of a unit of powered roof support; operation of the feeder and coal discharge in accord with the process chart of the powered roof support.

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