Studies of two-stage coal discharge with stepped-type powered roof support

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Abstract. The authors propose the powered roof support of the stepped type. Such design ensures safe and efficient mining, as well as complete extraction of coal from thick seams with coal discharge to the rear armored face conveyor. The paper describes physical simulation and numerical modeling of two-stage top coal discharge.

1. Introduction

Thick and gently dipping coal is commonly mined using the underground method in many countries such as China, Russia, Kazakhstan, Australia, Poland, India and other. In Russia such mines mostly have low capacity, due to many objective and subjective causes. Although wealth of field experience and fruitful research, the problem connected with increase in the safety and efficiency of mining thick and gently dipping coal seams yet remains to be solved.

In recent years, increasingly wider application is enjoyed by the technologies put forward in the former Soviet Union and in France. These technologies involve top coal destruction using the force of confining pressure and discharge of caved coal to armored face conveyor or to rear conveyor [1–9]. This approach reduces amount of development drivage and cuts down expenditures connected with longwall equipment. The longwall mining systems are given additional functions associated with control over discharge coal flow.

On the other hand, implementation of this technology is impeded by the requirements of complete discharge and the discharge process mechanization at the preserved safety and efficiency of longwall. Coal losses in caved zone in a longwall result in autogenous ignition of coal; for another thing, during discharge, coal is mixed with dirt rocks and its ash content grows.

In this connection, it is of concern to evaluate and work out specifications for new powered roof support and auxiliary equipment which enable efficient coal extraction at higher output per face, reduced coal losses and, accordingly, enhanced safety in terms of endogenous fire hazard.

This paper presents a new type of powered roof support with a canopy designed in the form of steps for efficient weakening, fragmentation and discharge of coal to the rear AFC [10, 11].
2. Unit of powered roof support of stepped type

The unit of powered roof support for extraction of thick and gently dipping coal with caved coal discharge consists of (figure 1): (1) supporting and discharging sections interconnected on the Π-shaped frame; (2) hydraulic legs at the top of which the guide structure case is mounted to adjust position of the canopy of the discharge section; (3) a canopy of the supporting section which is a rigid frame with the inner guide chambers of the face shearer and the rear-end extension-type shield operated by hydraulic jacks; (4) ripping knives on the top of the canopy. The discharge section consists of a T-shaped base connected with the base of the supporting section by a hydraulic jack along the axis of symmetry; hydraulic jacks; an arch-wise canopy with its front end always laid on the guide case. The canopy has a window (hole) for coal discharge.

A thick coal seam is divided into a cutting layer and a top coal layer (interlayer) which are cut as a single layer with top coal discharge. The face of the cutting layer is arranged at the seam floor and equipped with a stepped powered roof support, a shearer loader, an armored face conveyor and a rear AFC. First, the shearer loader cuts along the whole length and across the whole width of the cutting layer; this coal is not discharged. Behind the shearer loader, by the width of the cutting layer, the supporting section of the powered roof support is advanced toward the face. During the advance, the ripping knives cut top coal (interlayer), which adds stability to the powered roof support and weakens top coal thickness. The discharging section of the support is not advanced. The rear extension-type shield is pulled inside the canopy of the supporting section by the hydraulic jack. The, the hydraulic jack opens the gate of the discharge hole and caved top coal flows along an inclined chute to the rear AFC. Owing to to-and-fro motion of the rear extension-type shield, additional crushing of caved top coal takes place, and this coal is also ejected through the discharge hole. By the end of coal discharge, the hole is shut again, the discharging section of the powered roof support is advanced, and coal is discharged to the armored face conveyor through the window formed by retraction of the slide valve.
of the mobile section of the shield. After complete coal discharge, the next layer of coal is cut, and the cycle repeats (figure 2). In the specific geological conditions, longwall parameters such as cutting layer thickness, top coal layer thickness as well as the step of discharge can be adjusted.

![Figure 2](image)

**Figure 2.** Shearing and discharge of coal in longwall: (a) shearer loader cuts layer of coal; (b) face shearsers and anti-sloughing shields are pulled out; (c) supporting section of the powered roof support is advanced, position of the face shearsers is adjusted; (d) coal is discharged through the hole, oversize coal is crushed; (e) the discharging section of the powered roof support is advanced, coal is discharged behind the shield; (f) the armored face conveyor and the rear AFC are advanced, coal discharge is completed.

The proposed-design unit of the powered roof support for thick and gently dipping coal mining with discharge allows dynamic impact on top coal owing to unconventional structural features and due to application of the energy of confining pressure. Furthermore, it ensures safety of coal discharge using extension-type shields which are pulled out of the guide chambers of the arch-wise frame in the discharging section of the unit during advance of the supporting section, and shut clearances.
The feature of this approach is feasibility of simultaneous or alternating discharge of caved coal from two holes within the extraction cycle as per an accepted process flow chart. Furthermore, this unit of the powered roof support can be employed in thick coal seams as well, using only the frontal section and the conventional flow sheet.

In the mining system with coal discharge, parameters of discharge coal flow are very important. The caved top coal discharge can be optimized through:

- creation of caving and crushed coal zone above the canopy of powered roof support;
- enlargement of sizes and number of discharge holes;
- arrangement of conditions of free coal flow through discharge holes;
- availability of auxiliary mechanical tools for top coal crushing and fragmentation.

In modeling mining of thick and gently dipping coal along the seam strike:

- it is possible to achieve the fullest possible top coal discharge by multiple thrusting of top coal;
- as powered roof support is advanced off the assemblage room, coal loss with respect to the coal seam thickness is reduced;
- influence of abutment pressure is observable in 4–5 operating cycles-top coal is destructed ahead of the longwall face;
- after hanging and caving of the main roof rocks, it is possible that dirt rocks fall in the hole during coal discharge. To avoid this, it is advised not to aim at the maximum coal discharge through the hole. The ratio of coal discharge through the hole and slide valve should be about 1:1;
- top coal can fall in the face area; for this reason, the powered roof support should be equipped with a dynamic extension-type canopy group (brow);
- coal cutting by shearer can contribute to coal destruction above the powered roof support;
- expansion of the incompletely pulled-in frontal section and its successive total pulling-in produces contributes to top coal crushing and fragmentation.

Figure 3–6 demonstrate physical simulation results on top coal caving with discharge at various parameters of the system. In mining along the dip, no face sloughing was observed, and coal fell by gravity to the rear AFC. The model of the powered roof support had no mobile tail shielding - the design was stiff. This factor brings considerable errors in the study of the discharge coal flow parameters during physical simulation.

High-quality weakening of top coal and its discharge is promoted by: multiple alternating loads during advance and expansion of sections of the powered roof support; ripping elements; coal caving on the rear section canopy; coal oversize crushing by the face shearer; stimulation of top coal caving and formation of voids; caving on the tail shield; stage-wise coal discharge; large distance between the face and discharge holes.

Under comparable geotechnical conditions, the immediate roof caving is more chaotic in model 1 and more ordered in the reference model as against model 2. In model 1 versus model 2, coal loss with respect to the seam thickness is lower. Given a false roof, coal dilution is probable in model 1; model 2 has no false roof, thus dilution is absent.

Under comparative geological conditions, coal discharge is most efficient through hole in model 3 and through the rear slide valve in model 4. In model 4, the sections of powered roof support are advanced more easily. The level of coal loss and dilution is approximately the same in models 3 and 4.

The laboratory tests of the model proved that coal loss decreased as longwall advanced toward the dip of cleavage cracks in rock mass.
Figure 3. Physical model 1 for mining thick and gently dipping coal seam with easy roof along the strike.

Figure 4. Physical model 2 for mining thick and gently dipping coal seam with difficult roof along the strike.
Figure 5. Physical model 3 for mining thick and gently dipping coal seam with difficult roof along the strike.

Figure 6. Physical model 4 for mining thick and gently dipping coal seam with difficult roof along the dip (5 deg).
3. 2D discrete element modeling of coal discharge from thick and gently dipping seam

Despite considerable experimental and in-situ research advancement in the field of coal discharge, the topical problem is to select an adequate theoretical description of granular medium behavior for solution of problems on broken rock stability as well as on rock mass deformation in technologies with discharge. The discrete element modeling offers the most satisfactory results which are best similar to the test data [12, 13]. Based on DEM, the numerical analysis of coal discharge from thick and gently dipping coal seam was undertaken. Deformation of the test medium at the fixed moments of time to accord with discharge stages described above (roof support advance; top hole opening and shutting, as well as final advance) is depicted in Figure 7. The dark color marks coal, dirt rocks are painted grey. The structural elements of the powered roof support, which interact with coal and dirt rocks, are shown as solid segments.

**Figure 7.** Deformation of rocks at fixed moments of time in coal discharge from thick and gently dipping seam: (a) initial state; (b) advance of the supporting section of the powered roof support; (c) opening of top hole; (d) turn of chute and coal discharge through the top hole; (e) shutting of the top hole; (f) advance of the discharging section of the powered roof support.
4. Conclusions
The experimental and theoretical studies determine the level of change in operational losses, which allows finding optimal parameters for the mining technology for thick and gently dipping coal seams with controllable two-stage coal discharge for the powered roof support with the canopy of stepped type. This outcome is important for the ecology and coal industry in Russia.

The stepped design of the canopy ensures two-stage caving of top coal, crushing of coal overizes, as well as primary and final discharge of coal and rocks to the armored face conveyor and rear AFC. The two-stage discharge is advantageous for the formation of larger discharge funnels along longwalls as compared with the conventional types of powered roof support with discharge.

The tests find that the ratio of coal flows through the discharge hole and slide valve of the mobile shielding should be 1:1. In this case, caved dirt rocks exert destructive effect on caved top coal while remain off the discharge funnel at the preliminary stage of coal discharge.

It is shown that the two-stage coal discharge, subject to functional assemblies of unloading-and-discharge system of the powered roof support, thickness of top coal, pattern of caved rocks behind the support, enables minimization of loss and coal ignition risk in longwalls.

Based on the discrete element method, the two-dimensional numerical model is constructed for coal discharged under caved overburden with regard to advance of the powered roof support. The process of coal dilution with open top hole is illustrated.

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