Development and substantiation of parameters of multifunctional mobile roof support

V I Klishin and Yu V Malakhov
Institute of Coal, Federal Research Center of Coal and Chemistry, Siberian Branch, Russian Academy of Sciences, 18 Sovetskiy pr., Kemerovo, 650065, Russia
E-mail: klishinv@icc.kemsc.ru

Abstract. The paper describes the technical parameters and requirements for the basic element of longwall systems for mining thick and steeply dipping seams and for extraction of coal from safety pillars. The proposed multifunctional mobile roof support ensures safe and efficient operation of mines in complicated geological conditions. The authors offer classification of the performance capabilities of the multifunctional mobile powered roof support.

1. Introduction
Despite the increasing role of renewable sources of energy in the global economy, coal ranks high in the fuel and energy balance in many countries. Currently, 37% of energy in the world is produced by coal-fired power stations [1]. As of 2017, the mature economics of the world feature coal percentage in the power engineering as follows: USA – 30%, Germany – 37%, Japan – 33%, South Korea – 46%, China – 67% and India – 76% [2]. By experts’ estimates, the most favorable situation in the long term will be in the Asia–Pacific region where coal-fired power generation makes 60% while the annual increment in the power consumption is 5% [2].

In accord with the Energy Strategy of Russia up to 2035 [3], with regard to the anticipated economic upswing, the internal consumption of crude energy in the country will grow by 17% while the electric energy demand will rise by 36% by 2035. As of 2017 coal-fired power in the fuel balance of Russia makes 14% [2]. In view of the long-term prevalence of oil and gas in the export of Russia to the global markets of energy sources, it is expected that the national market requires more coal from the domestic producing companies.

Apparently, as an energy source for electric power generation, coal now and in the long run will be vitally important both in the world and in Russia.

The coal industry development program [4] provides increment in the annual coal production output to 410–480 Mt by 2030. The top priority objectives of the Program include sustainable engineering and advancement of technologies and equipment aimed to enhance mining efficiency, as well as application of technological innovations.

2. Relevance
The proven coal reserves in the Kuznetsk Coal Basin alone, down to a depth of 600 m total 67.1 billion tons, including 17.6 billion tons (to 25%) mineable by the opencast method [5].

The analysis of the resource base and experience of coal mining in Russia shows that approximately 1/3 of proven coal reserves are uneconomically recoverable and occur in difficult ground conditions [6]. The current market of mining equipment lacks modern high-productivity
longwall systems for coal extraction in the conditions of complicated geology, including thick steeply dipping coal seams and safety pillars. Coal mining is scant under complicated geological and geotechnical conditions. In the meanwhile, in Kuzbass solely, the introduction of advanced technologies and methods for mining thick coal seams at dip angles from 36 to 55° would make it possible to put into operation 2.2 billion tones of proven reserves (1.3 billion tons of commercial reserves) [5].

Given the anticipated increase in coal consumption for power engineering, it will be inevitably required to have new project designs on introduction of geologically complex reserves into operation [7]. It will be necessary to have new process solutions and equipment for efficient use of accessed reserves and expedient extraction of new-involved reserves in difficult geological conditions at minimized loss of valuable mineral in extraction.

One of the promising ways of advancing technologies for coal extraction from pillars and under complex geological conditions is application of hydraulically driven mobile support for longwall top coal caving [6, 8]. This technology is based on physical destruction of coal using confining pressure. Coal caving above or behind the support is controllable.

The longwall top coal caving system for coal mining under complicated geological conditions, including thick steep-dipping seams, and for extraction of coal from safety pillars can use a mobile support-and-shield module [6, 9, 10]. This module is based on the earlier proposed hydraulically driven mobile roof support for junctures between sublevel drifts and coal discharge areas as well as for shielding sidewalls in underground excavations [8]. The mobile-type support-and-shield module allows automated control of the mining process, with no personnel present in the working zone, including robotization of separate operation [10–13].

The long-term sustainable development in the coal mining industry requires solving interrelated problems connected with design and substantiation of outfit for safe and efficient extraction of coal reserves in complicated geological conditions.

3. Substantiation of design parameters

The existing longwall equipment of domestic manufacture for mining thick steeply dipping coal seams is inefficient and unsafe in operation in complicated geological and geotechnical conditions. For this reason, creation and improvement of technologies and equipment for coal mining in difficult ground conditions is in progress.

The proposed design solutions for thick steeply dipping coal seams should be economically and technologically able to meet competition. They should rely upon the science-based approaches including highly productive and adaptable coal mining technologies capable to ensure complete coal extraction at limited investment [14].

For mines operating in thick steeply dipping coal seams, the technology of top coal caving with sublevel drifts is formulated and scientifically validated [8, 9]. This technology uses drifts driven on the seam floor at the bottom of each extraction panel (figure 1). This allows full-thickness coal cutting, including top coal and interlayers. Furthermore, completeness of top coal caving is improved as it is carried out across the whole area of the seam thanks to the mobile powered roof support equipped with control of discharge coal flows.

The introduction of this technology in practice needs proper equipment. Fully mechanized longwall mining system in difficult ground conditions should be capable to extract thick and steep coal seams as well as coal from safety pillars. Moreover, the equipment should ensure increased safety and efficiency of mining.

The operational parameters of such equipment should be aimed to solve the target problem of coal extraction at completeness not less than 80%. The full-thickness cutting of a coal seam, without its division into layers should contribute to high concentration of mining operations and to reduction in operational through-thickness coal loss from 30 to 15%. Application of a confining pressure and self-caving of coal will save 25–30% of energy input in coal mining. For another thing, this technology
will diminish the volume of development heading and, thus, the cost of drivage and maintenance of entries.

Figure 1. Top coal caving technology with mobile powered roof support.

The operation parameters of mining safety with such equipment should lessen risk of endogenous fires and eliminate use of explosives. The equipment is to be able to work with such methods of rock mass weakening as: directional multi-stage hydraulic fracturing [15], vibro-seismic method using seismic vibrators.

The equipment design parameters should be capable to ensure:

• Advance of powered roof support without loss of contact with the roof;
• Mechanization of roof support and control of roof caving;
• Hold back of caved rocks from the working area in a longwall;
• Enough room for other machines and personnel;
• Independent compliance of hydraulic props, as well as separate unloading and expansion of units;
• Protection of the working area from caved rocks from the side of mined-out area;
• Mobility;
• Transverse and longitudinal stability, including when in advance;
• Direction of advance and adjustability in the horizontal and vertical planes of longwalls, including curved;
• Free and safe access for maintenance and repair of units and parts, or replacement of hydraulic jacks and props on-site;
• Automated and remote control of equipment, including robotic technologies of unmanned mining [16].

4. R&D
The basic element in the above-described longwall mining system is a powered roof support for sublevel caving of thick and steep coal seams [17] (hereinafter, mobile roof support).
The proposed powered mobile roof support (figure 2) is composed of two units with a canopy in the form of bearing beams 1 on the cross frames 2. The cross frames are pivotally connected with stabilizing hydraulic jacks 3 and hydraulic props 4. The spacing hydraulic jacks 5 are also pivotally connected with the cross frames 2. Bearing slides 6 are mounted on the hydraulic props 4 and jointly make a side guide of the unit. The bearing slides 6 are forced to the sidewalls by the spacing and stabilizing hydraulic jacks 5 and 3. The hydraulic props 4 with their feet 7 put on the floor of an underground excavation ensure the roof support. The feet allow the props to step over obstacles on the uncleaned floor. The units are interconnected by travel hydraulic jacks 8 placed between the cross frames of the units and meant to enable travel of the units along a drift.

As against [17], this mobile roof support is equipped with a canopy group for dosing top coal discharge. The canopy group consists of leadstocks 9 pivotally connected with the bearing beams 1 and hydraulic jacks 10 connected to the cross frames 2.

![Diagram of the mobile powered roof support](image)

**Figure 2.** Mobile powered roof support.

The main design parameters of the mobile roof support include:

- **L1** – length of the main canopy, should be sufficient to support roof in the working area of the unit operation and to enable arrangement of longwall equipment;
- **L2** – spacing of hydraulic props, should be shorter than the length of the main canopy by 2 increments of advance at the least;
- **L3** – length of the canopy group, should ensure dosed discharge of top coal and be not less than 2 increments of advance;
- **s** – increment of advance of a unit, should not be less than the axle spacing of the neighbor props;
\( b \) – width of the support unit, should suit operation of the roof support in excavations 4 m wide;
\( h \) – height of the extended-height unit, should suit the dimension of a drift.

After weakening, rehandling and conveying of coal, the units of the mobile roof support are advanced. First, the thrust is removed, and the props 4, stabilizing jacks 3 and spacing jacks 5 are retracted in one unit of the mobile roof support. The side guides in the form of the bearing slides 6 are taken off the sidewalls and the props 7 come clear of the floor. The unit, by gravity, falls with its bearing beams 1 on the cross frames 2. After that, the unit is advanced by the travel jack 8 by the pre-set increment. In the horizontal plane of the excavation, the advancing unit is ruled using the spacing jacks 5. When the advance is accomplished, extension of the props 4, stabilizing jacks 3 and spacing jacks 5 is executed, which ensures reliable roof support and sidewall holding. The second unit of the mobile roof support is advanced in the same manner [17]. The dosed top coal discharge is performed when all units are thrust. The leadstocks 9 during coal discharge are operated by the canopy group jacks 10.

The proposed mobile roof support possesses some special technical features which improve its operational capabilities in complicated geological conditions, such as:

- Permanent floor-to-roof thrust owing to the valve assembly meant to lock the head ends in the props;
- Feasibility to enhance the thrust of the unit sideways using the telescopic cross frames, with transverse extension relative to the longitudinal axis of the unit using the spacing jacks;
- Adaptability of the side guides made of longitudinal guide slides to the cross section of the excavation owing to the pivotal connections;
- Protection of the props and rods from cross and side loads and damages owing to telescopic housing.

The technical parameters and engineering solutions embedded in the structure of the mobile roof support ensure reliable support of the roof and fencing of the sidewalls in underground excavations. The structure of the roof support unit is kinematically stable both in advance and in thrust.

Regarding the functionality and interactions with sidewalls, this mobile roof support can be assumed as the shield-and-support type. The elements of the units of such support are pivotally interconnected, and the supporting and shielding elements conjointly create a working area in longwall [18].

In the design of the proposed mobile roof support units, projection of the supporting part on the plane of the seam is larger than projection of the shielding part [19]. For this reason, this is the support-and-shield unit. Actually, thanks to the independent and permanent thrust provided by the props equipped with the valves, the mobile roof support preserves stability of roof rocks above the working area and allows ground control through complete caving behind the shielding elements. Due to the specific arrangement of the hydraulic props, the proposed mobile roof support offers a larger working area suitable for comfortable accommodation of necessary equipment and clear passage of personnel. The support is applicable in mines with increased gas release as it is well ventilatable.

The proposed mobile roof support performs all standard functions, namely, ground control, roof support and shielding of the working area from caved roof rocks.

Although one of the support units loses contact with roof when advanced, the support as a whole is assumed as the fixed roof contact support type. Owning to the proposed engineering solution, the roof support is permanent, and the mobile roof support is applicable both in case of stable and unstable roof. Structurally, the mobile roof support is composite as it is composed of two units mutually connected kinematically and by hydraulic travel jacks. Regarding the method of advance, the support is of mobile type.

Summarizing, we classify the proposed mobile roof support as the mobile compound powered roof support-and-shield.

This roof support can also be used in mine intersections. For instance, to support roof at the juncture of a drift and longwall to ensure advance of AFC [18]. Currently, the compound juncture roof
support enjoys wider application, this support consists of two and more kinematically connected units and is advanced in drifts using double-action hydraulic jacks.

Thus, judging from the engineering solutions and functions embedded in the structure, the proposed mobile roof support is multifunctional.

5. Conclusion
Given sustainable development of the coal industry, the nearest future will be facing a demand for equipment capable to ensure practical application of science-based technologies for coal mining in difficult geological conditions, including extraction of coal from steeply dipping seams and from safety pillars. Application of the innovative equipment to mining under complicated geological conditions should solve some key problems of the coal industry, namely, the improvement of safety, productivity and efficiency of mining, as well as the transition to unmanned technologies [21].

The proposed multifunctional mobile powered roof support has its performance and engineering data in compliance with modern standards of safe and efficient operation in the conditions of difficult ground. The multifunctional mobile roof support can be included in longwall mining systems for thick and steep coal seams, or for extraction of coal from safety pillars, or serve as a roof support at junctures in coal mines.

Thus, the R&D project on the multifunctional mobile powered roof support is relevant and meets the objectives of advancement in the coal mining industry.

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