UDC 622.33: 622.4

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REPRODUCTION OF THE LONGWALL PANELS: MODERN REQUIREMENTS FOR THE TECHNOLOGY AND ORGANIZATION OF THE DEVELOPMENT OPERATIONS AT COAL MINES

The authors point at the criticality of timely reproduction of longwall panels in coal mines toward sustainable and high-rate coal mining based on the utilization potential of modern longwall equipment. A case-study of SUEK-Kuzbass mines shows that there is a need to change approaches to improvement of economic efficiency and competitiveness of coal mining and to shift from the common practice of production cost reduction to productivity enhancement through implementation of high-performance equipment capabilities. Efficiency of road heading in mines of SUEK-Kuzbass is analyzed, and the main causes of long downtime in operation of modern high-performance continuous miners (CM) or continuous bolter miners (CBM) are identified. Recommendations have been developed for improved planning of preparatory works in mines and for introduction of significant action time margin to eliminate downtime when actual drivage performance lags behind the planning data. The action time structure of modern CBM is presented, and recommendations are given on CBM efficiency evaluation as actual action time in cutting road face rocks. The application areas of various modern CBM types are justified. Recommendations are proposed for changing the parameters of longwall panels and to change to multi-entry longwall panels in order to increase efficiency of preparatory works and actual coal production. The authors describe expediency of widespread use of shuttle cars to improve efficiency of haulage of rocks and materials. The organizational and technological principles of the efficiency increase in preparatory works in coal mines are substantiated.

Keywords: *underground mining, coal seam, continuous bolter miner, technical-and-economic indices, equipment, work management, downtime, machine utilization factor, productivity.*
DOI: *10.17580/em.2020.02.05*

Introduction

The modern, reliable and high-power equipment introduced in coal mines in Russia has ensured peak outputs per faces. For example, in mining of thick and gently dipping coal seam 50 in Yalevsky Mine, the complete longwall systems reach capacity of 1–1.6 Mt/month and sometimes produce up to 65 kt of coal per day [1]. However, despite high average monthly capacity, the annual capacity of complete longwall systems is not higher than 6 Mt. Such unbalance is explained by long idle periods of high-performance longwall equipment due to decelerated reproduction of longwall front and late preparation of new working areas [2]. Low efficiency of drivage is a common problem [2–7] and it becomes even more acute at higher outputs per face in longwalls fully equipped with modern high-performance machines.

The analysis of drivage efficiency in mines of SUEK-Kuzbass shows that drivage velocities fall behind the rates of advance in longwalls, which restrains and slows down coal production. For instance, in 2018 the average rate of drivage in mines was 160 and 210 m/month with selective and multi-point attack miners, respectively. In the meanwhile, the rate of advance in a longwall 400 m long in coal seam 50 in Yalevsky Mine ranged from 320 to 725 m/month. For the well-timed reproduction of the longwall front, even in preparation of working areas by drivage of paired roadways, the rate of drivage should be 2.3–2.8 m per 1 m of advance of the longwall face, which is impossible even in counter heading or using four miners in drivage of paired roadways in longwall panels.

In such situation, an obvious solution is purchase and introduction of modern drivage equipment manufactured by world's top producers, namely, continuous and bolter miners capable to ensure drivage advance by 1000–2000 m per month in favorable operating conditions. Such rate of drivage can help solve the present-day problem connected with preparation of working areas. At the same time, case history of the advanced miners in SUEK-Kuzbass mines shows that it is also necessary to modify and improve process flowcharts, as well as drivage planning and management. In this respect, this study aims to develop and justify recommendations on improvement of management, technological reliability and efficiency of drivage operations toward higher reproductive capacity of longwall faces, as well as for stable and high-rate coal production in mines of SUEK-Kuzbass.

Modern trends in drivage technology and equipment

Technological advance in coal mining has resulted in higher outputs per face, increased rates of advance and heights of mining. Currently, the output per face can reach 65 kt/day [1], the rate of advance—70 m/day [8] and the mining height—8 m. Modern mining machines are heavier and larger than they were earlier. High-rate coal production has conditioned increased rates and cross-sections of longwalls. Thus, new mining machines, such as satellite bolters and bolter miners have been engineered [8] to ensure independent operation of a few longwalls, and to enable concurrent coal cutting and roof bolt installation. Developed in the 1990s (Sandvik Alpine Bolter Miner ABM20), the continuously improved and modified mining machines have shaped a new standard of high-capacity equipment, which has resulted in gradual rejection of earlier models. For instance, mines in the United States abandoned earlier popular Joy continuous miners 12CM and 14 CM [8].

American mines currently use two flowcharts of mining machines: (1) continuous operation miner; (2) alternation of

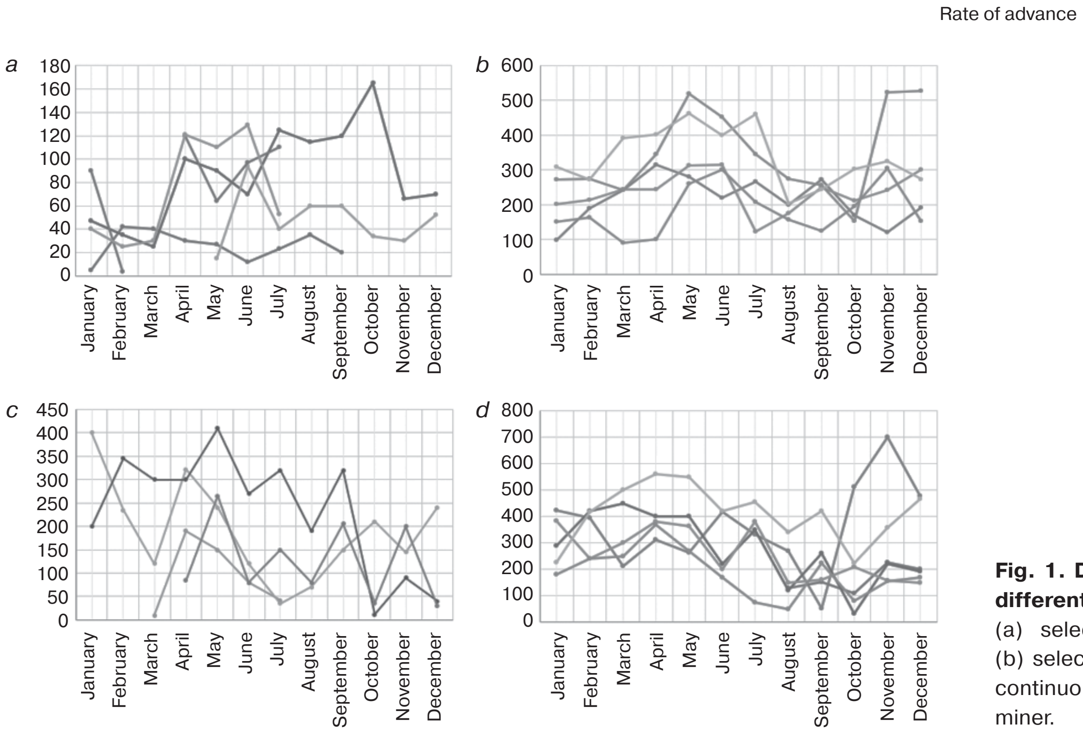

Fig. 1. Drivage dynamics with different mining machines:
(a) selective cutting of rock; (b) selective cutting of coal; (c) continuous miner; (d) bolter miner.

miner and bolter in longwall. In the second flowchart, longwalling without bolting is carried out for a distance of 6.1 to 12.2 m. The maximal achieved capacity of bolter miners is 76 m/day. For the complete utilization of the efficiency of miners, American mines combine bolter miners with flexible conveyor trains. The in-situ tests show that such equipment assemblies reach a capacity from 61 to 111 per a shift 12 h long [8]. At the same time, the standards imposed on operating conditions and maintenance of such equipment are very high. It also should be mentioned that the mining technology and equipment are being persistently improved [8–25].

It is very difficult to ensure the same performance of such equipment in Russian mines due to much more difficult geological conditions. The major complicating factors are unstable enclosing rocks and high gas content of coal. Despite a substantial performance gap between mines in Russia and in the leading coal-mining countries, average rates of drivage reached in these countries to be achieved by drivage teams in Russian mines is a first-order condition of high competitive strength of Russian mining companies in the international market.

The growth prospects of underground coal mining in Russia are naturally connected with introduction of multi-drift preparation of working area from three sides of a longwall panel. This approach enables more efficient haulage, methane emission control and equipment erection/teardown flowcharts owing to purpose-based differentiation of roadways, and eliminates diagonal ventilation cross-cutting. The work content of drivage in this case requires using modern miners in combination with self-propelling cars or flexible conveyor trains to ensure high rates of drivage in straightways. In delineation of a longwall panel from three sides, the faces of all three entries should be handled by a single drivage team for the coordinated operation of the three faces and to eliminate downtimes if one face runs ahead of the other, by prompt redeployment of equipment and personnel to slow face areas. The multi-drift preparation from three entries is a key flowchart in mines in the USA, while paired drift drivage is only involved under conditions of increased dynamic hazard, in deep-level mining at a depth below 350 m, given highly strong and difficult roof rocks, with yielding pillars between the paired drifts thanks to small width of the pillars (less than 9 m).

Drivage in SUEK-Kuzbass mines

Being continuously updated, series-produced road-heading machine KP21 at Kopeysk Machine Building Plant ensured higher rate drivage and set up a few record work data in SUEK-Kuzbass mines. In the most efficient roadways, the rate of advance reached 700 m/month though average performance rarely exceeded 200 m/month.

High rates of advance (to 35 m/day and 800 m/month) in longwalls equipped with advanced high-performance mining machines dictated reequipment of SUEK-Kuzbass mines to ensure timely preparation of working areas. Obsolete road-heading machines K21 were replaced by Sandvik MB670-1 bolter miners. The latter is a 2015 modification meant for accelerated delineation of longwall panels. The introduction of the modern bolter miners increased the rate of drivage 1.5 times. Nevertheless, the average performance of rock drivage teams, though equipped with advanced machines, remains intolerably low and falls far behind the performance data achieved by top coal mining companies.

The efficiency analysis of operation of different mining machines in SUEK-Kuzbass mines in 2019 discloses drastically unstable operation of most drivage teams (**Fig. 1**). The rate of drivage in accessing roadways in dirt rocks ranges between 20 and 160 m/month (Fig. 1a). In actual coal cutting using machine KP21, the rates of advance also vary within a wide range (Fig. 1b). Essential fluctuations in drivage rates are observed with continuous miners Joy12CM30 too (Fig. 1c). The rates of road heading with bolter miners MB 670-1 are higher but also unstable in time (Fig. 1d).

Low efficiency of drivage and, as a consequence, ill-timed preparation of new working areas are the major constraints of progressive coal production in underground high-rate

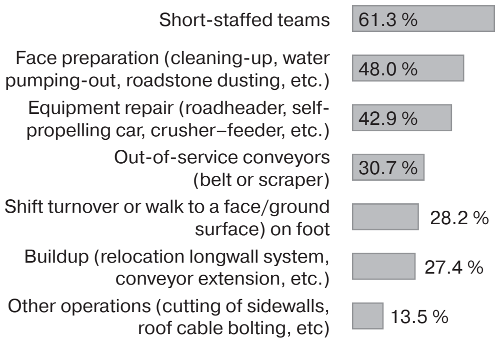

Fig. 2. Mine downtime per grouped causes

extraction of gently dipping coal seams using modern high-performance machinery. The difficulties most often arise in longwalling at the rate of the face advance more than 40 m/day. Such rates of advance are atypical of SUEK-Kuzbass mines where the only longwall can sometimes reach an advance rate of 35 m/day (seam 50 in Yalevsky Mine). In the meanwhile, the economic damage due to idle time of high-performance equipment in SUEK-Kuzbass mines exceeds USD 100 thousand/day, and the unscheduled downtime in each high-output longwall can last for 90 days and more. In this connection, it is highly critical to ensure well-timed preparation of longwall panels at minimized downtime as the effectiveness of this problem handling governs the competitive ability and even the staying power of underground power-generating coal mines in the conditions of unsteady market.

The common approach to lowering cost of coal production based on reduction in working expenses results in the loss of efficiency of productive processes, including drivage, in the downtime of high-capacity machines and in a substantial increase in disbenefit due to prolongation of mining period, or owing to a decline in output, which finally leads to a dramatic increase in the mine product cost. To avoid discontinuity in longwall operation, it is expedient to increase amounts used to purchase and apply the best available technologies and equipment (the basic and auxiliary mining machines and transport systems) required for the efficient drivage, to introduce the recent approaches to stimulation and motivation of personnel, as well as to attract highly professional people to ensure well-time preparation of longwall panels and continuous longwall operation.

Low efficiency of continuous roadheaders: causes and elimination

The main cause of the low-rate drivage is inefficient utilization of modern roadheaders (See Fig. 1) due to lack of drift miners and imperfection of process flowcharts (**Fig. 2**) which are mostly disadvantageous for:

- long idle time of equipment due to inefficient implementation of auxiliary operations, lack of auxiliary facilities and materials, ill-timed personnel transportation;
- downtime of mining machines in paired roadway heading due to lag of one roadway when the mining machine cuts a face entry;
- obsolete flowcharts of drivage (for instance, use of scraper conveyors SR-70);
- low efficiency of water inflow control in heading faces, which results in floor soaking, formation of treadways and perpetual maintenance of satisfactory operating condition of floor in roadways;
- use of drifters to carry out auxiliary and extra operations, and hand haulage of materials to face sites.

Performance analysis of modern mining machines in thick and gently dipping coal seams shows that even fully populated mining teams suffer from long downtime of machinery, and action times of the miners makes not more than 32% of the total worktime of the machines while the set target standard is 60%.

Aimed to eliminate these disadvantages of drivage flowcharts, it is necessary:

- to use efficient delineation patterns for longwall panels, using bolter mines for longwall operations and continuous miners for driving diagonal vent cross cuts (in paired drifting);
- to use special flowcharts for short roadway construction (to 500 m long), without conveyors, using two self-propelling cars, which coal rehanding from one car to the other to shorten the haulage distance;
- to improve efficiency of mine support installation, which takes up to 75% of the total drivage cycle, using optimized support designs, and without cable bolting of roadway face area (in operation beyond the zones of increased overburden pressure and abutment pressure);
- to apply advanced flowcharts, with scraper conveyors SR-70 substituted for self-propelling cars (except for coal seam angels more than 12 deg);
- to increase operating efficiency of drift miners through reduced amount of manual labor (elimination of manual haulage of rock bolts and long-span installation of steel straps), walking of mine personnel for long distances on foot, attraction of workers from auxiliary service sites to implement erection, construction and repair;
- to increase the fleet of self-propelling cars for rock haulage, as well as load–haul–dumpers for creation of favorable operating conditions (cleaning-up) and for material haulage using the purchased up-to-date and reliable equipment;
- to ensure efficient water inflow control and drainage, and higher performance of pumping to eliminate water accumulation in roadways.

These recommendations can help improve efficiency of drivage teams but are incapable to enhance performance of equipment. In this regard, the necessary condition is to modify approaches to drivage planning and management.

Recommended approaches to planning and management of drivage

In the authors' opinion, enhancement of equipment effectiveness is a key factor of high-efficiency in underground coal production. There are a few approaches to the efficiency evaluation of equipment, based, as a rule, on the equipment time estimate—operation time, or the percentage of the operation time, or productive time ratio. Yet, the present paper authors believe these approaches only determine working hours of machines per shift or day rather than efficiency of the machines within these working hours. In this context, a simpler estimation of the rate of the roadway face advance is a more effective approach. For the efficient implementation of potential of roadheaders, it is necessary to analyze their action time structure. For any type of roadheaders, the action time structure can be represented by the diagram in **Fig. 3**. The actual action time, which is used as

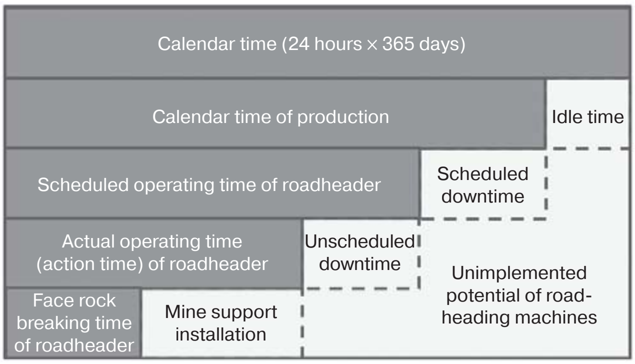

Fig. 3. Structure of action time and downtime of roadheaders

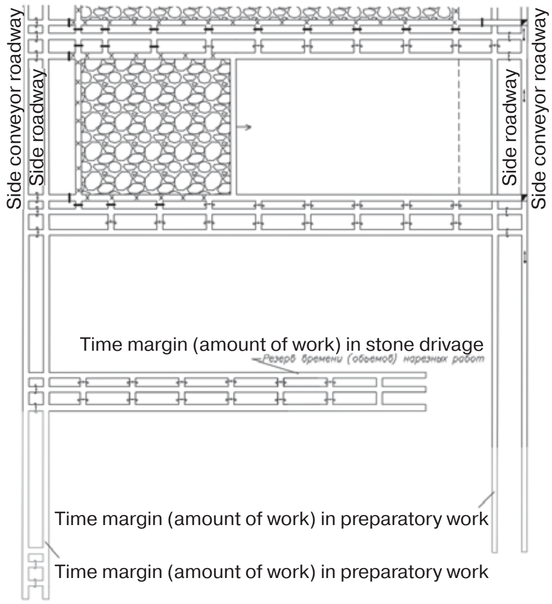

Fig. 4. Time margin due to early preparation

a reference point in drivage planning and efficiency evaluation, is governed by the duration of scheduled and unscheduled downtime periods, which are conditioned by the drivage technology, equipment and organizational management. At the present time, SUEK-Kuzbass mines evaluate utilization of bolter miners with the set target action time as 60%. However, this approach neglects efficiency of performance of the machines within this action time. The major mission of the up-to-date high-performance roadheaders is to increase in the rate of drivage by means of synchronization of basic operations. In this case, the time of efficient operation of a bolter miner should only be assed as the time of the roadway face cutting while the rest of time should be assumed as the downtime due to inefficient use of the machine. This approach, earlier proposed by the present authors to estimating utilization completeness of longwall systems [2], is applicable in the case under discussion as it also allows comparing process flowcharts and selecting the most efficient flowchart toward the ultimate implementation of capabilities of the advanced roadheaders.

A necessary condition of longwall reproduction under high uncertainty and difficulty of geological and geotechnical conditions is the effectivization of longwall planning by setting substantial margins of time or quantity of drivage (**Fig. 4**) in order to level down the consequences of a significant lag of the actual work data behind the projected performance.

For example, it is possible to avoid downtime of high-productive longwall equipment by means of formation of a time margin not less than 2 months from completion of all preparatory work in a new working area to start of equipment teardown in a mined-out area. With such time margin set, the impact of the slowdown in the project rate of drivage can be minimized subject to actually achieved drivage rate in specific geological conditions and with regard to additional complicating factors (operation in the zones of increased overburden pressure, or in the influence zone of faulting).

To avoid effect of side roadway drivage in delineation of longwall panels, the side roadways should be advanced relative to a new longwall not less than by the length of this longwall (See Fig. 4). Considering actual rates of advance of longwalls, such margin time can be not longer than 6 months, but this can help avoid long idle time of high-performance equipment. To ensure timely and fast movement of roadheaders to new roadways after completion of work, the rational paths should be planned for the machines beforehand, and cleaning-up should be carried out in time to ensure movement of the equipment without teardown. It should be mentioned that bolter miners to be relocated without teardown need large cross-section roadways; at the same time, the practice has shown that teardown increases duration of placing the machine in operation at new sites to a few months.

Even more spare time for preparation of new longwall panels can be provided by the increase in the length of longwalls to 400 m. This approach is most efficient in mining coal seams of average thickness. For instance, in mining coal seams to 3 m thick, around 30% of all longwalls in the USA are longer than 400 m (the maximal length is 482 m) [8, 26].

Employment of modern and reliable machines optimizes the face operation mode as a whole shift can be appointed a repair and maintenance shift. Repair and maintenance can be implemented if and when necessary. Such organizational management of drivage can increase utilization efficiency of modern mining machines and accelerate the rate of drivage.

Conclusions

The implemented research allows formulation of basic recommendations on drivage technology and management in high-output coal mines as listed below.

1. Selection and validation of technology, schedule, spatial layout and planning decisions should be based on the criterion of maximum utilization efficiency of modern high-performance equipment. The utilization efficiency of the advanced mining machinery in the best mines in Russia is currently less than 25% of the theoretical value (estimate fulfilled by the procedure proposed by this paper authors earlier [2]), which is governed by low efficiency of roadheaders the action time of which is not more than 32%. The extent of damage (profit gap) due to downtime of high-performance longwall and drivage machines in high-rate coal mining can exceed 1 BRub per mine annually.

2. The ineffective utilization of road-heading machines is a major constraint of increased efficiency in underground coal mining with advanced longwall systems. It is highly critical for mine management to grasp the importance of drivage

operations and to give heightened attention to road heading (equally with longwalling).

3. A majority of mining companies undertake coal production cost saving based on reduction in production expenses, which leads to decreased efficiency of process flowcharts, to downtime of high-performance equipment and to appreciable economic disbenefit many times higher than a temporal effect of local cost cutout.

4. Selection and justification of efficient technologies should be based on the proposed action time structure and actual drivage time of a roadheader (face cutting in roadway). The proposed approach provides the efficiency estimate of modern road-headers which perform some basic operations simultaneously, and the efficiency estimate of process flowcharts and management of road heading.

5. In the conditions of high uncertainty and variety of complicating geological and geotechnical factors, enhanced efficiency of drivage planning can only be ensured through formation of margin time or amount of drivage to level consequences of the considerable gap between the planned performance and actual drivage data.

Thus, there exists a substantial potential for an appreciable improvement of efficiency and competitive capability of underground coal mining in Russia. This potential can only be implemented based on improved production management aimed to enhanced utilization of up-to-date mining machines.

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