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Extraction of Inclined Exit Ledges in Coal Mines in Presence of Mobile Crushing and Conveyor Complexes

D. Shibanov[a], A. Agaguena*[a], T. Annakulov[b]

[a] St. Petersburg Mining University, St. Petersburg, Russia
[b] Tashkent State Technical University named after Islam Karimov, Uzbekistan

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ABSTRACT

This article presents data on main technological fleet of excavation-loading equipment of mining enterprises of Uzbekistan, which traditionally are consumers of open-pit rope excavators of ECG type. Uzbekistan is traditionally consumer of open-pit rope excavators of ECG type. The data on experience of operation of open-pit hydraulic excavators by mining enterprises of Uzbekistan as of 2022 is given. The methodology of determination of time of working out and productivity of excavator at development of inclined exit ledge in conditions of coal mine Angrensky (Uzbekistan) is given. The calculation of time of working of the exit ledge is made and the average operational productivity of the excavator is determined. The technology of ledge mining by longitudinal drifts with the use of mobile excavator-crushing complexes at the lateral location of the bottom-hole conveyor and the presence of a mobile interstage loader with consecutive mining operations on two horizons is presented. According to the given technological scheme the methodology of determination of the full working cycle of the complex is recommended. The estimation of excavator bucket filling coefficient at different face height and different depth of bucket penetration into the face is carried out. A mathematical model for determining the area of the digging segment of a quarry excavator is developed. The mathematical model of definition of the area of excavation volume for a single digging cycle considering the depth of bucket penetration into the face is proposed for the refined estimation of face parameters.

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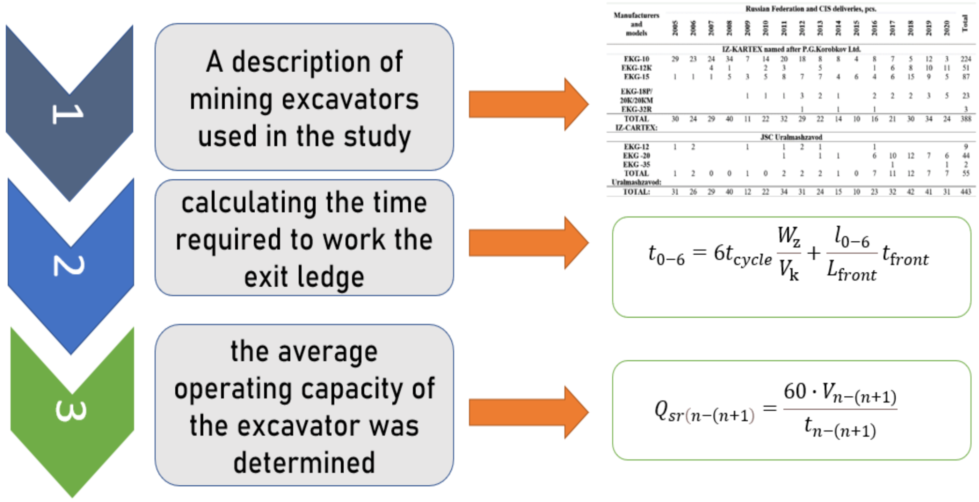
Graphical Abstract



Manufacturers and models	Russian Federation and CIS deliveries, pcs.																
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
IZ-KARTEX named after P.G.Korobkov Ltd.																	
EKG-10	29	23	24	34	7	14	20	18	8	8	4	8	7	5	12	3	224
EKG-12K			4	1		2	3		5			1	6	8	10	11	51
EKG-15	1	1	1	5	3	5	8	7	7	4	6	4	6	15	9	5	87
EKG-18P/ 20K/20KM					1	1	1	3	2	1		2	2	2	3	5	23
EKG-32R								1		1		1					3
TOTAL IZ-CARTEX:	30	24	29	40	11	22	32	29	22	14	10	16	21	30	34	24	388
JSC Uralmashzavod																	
EKG-12	1	2			1		1	2	1			1					9
EKG -20							1		1	1		6	10	12	7	6	44
EKG -35													1			1	2
TOTAL Uralmashzavod:	1	2	0	0	1	0	2	2	2	1	0	7	11	12	7	7	55
TOTAL:	31	26	29	40	12	22	34	31	24	15	10	23	32	42	41	31	443

$$t_{0-6} = 6t_{cycle}\frac{W_z}{V_k} + \frac{l_{0-6}}{L_{front}}t_{front}$$

$$Q_{sr(n-(n+1))} = \frac{60 \cdot V_{n-(n+1)}}{t_{n-(n+1)}}$$

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*Corresponding Author Email: *wahabtounssi40@gmail.com* (A. Agaguena)

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1. INTRODUCTION

The primary mining nations within the former Union of Soviet Socialist Republics (USSR) encompass Russia, Kazakhstan, Uzbekistan, Armenia, and Kyrgyzstan. The countries represent the greatest geographical areas globally, characterized by their distinct deposits of minerals and hydrocarbons. The countries that emerged after the dissolution of the Soviet Union are responsible for most of the mineral production in various sectors such as oil and gas, energy, chemical, metallurgical, and construction industries (1-3).

The countries of post-Soviet occupy the first three places in the world in terms of reserves of diamonds, precious metals, rare metals, and rare earth elements. In the world reserves of liquid hydrocarbons, the share of the countries of the former Soviet Union was about 25 percent: natural gas, about 35 percent; coal reserves, about a quarter of the world; iron ore, more than a third; chromium, nine percent; manganese, a third of the world reserves; nickel, about a quarter; cobalt, fifteen percent; lead, and zinc, twenty percent each (4).

As for the distribution of mineral reserves in the countries of the former USSR, their distribution is objectively characterized as extremely uneven. Thus, the largest mineral reserves (liquid and gaseous hydrocarbons, copper, nickel, tin deposits, diamondiferous pipes, placers, etc.) are concentrated in the main mining regions of Russia. Uranium, copper, and gold reserves are concentrated in the Republic of Uzbekistan. The largest deposits of uranium, chrome, zinc, lead, and tungsten ores are in the Republic of Kazakhstan.

The main technological fleet of open-pit excavators in Uzbekistan is characterized by the prevalence of electromechanical excavators manufactured by UZTM-KARTEX. The enterprises of Uzbekistan are traditionally the key consumers of UZTM-KARTEX products, which have been supplying the country since 1970.

UZTM-KARTEX manages the Russian manufacturers of electric mining excavators, PJSC Uralmashzavod and Korobkov IZ-KARTEX LLC.[7-9]

As part of a single group of companies, Uralmashzavod and IZ-KARTEX are the monopoly representatives of electric mining excavators in the post-Soviet space and control 81% of the market in Russia and neighboring countries. The dynamics of excavator deliveries by UZTM-KARTEX Group companies are presented in Table 1.

Since the merger of Uralmashzavod and IZ-KARTEX, there has been an increase in the production of electric mining excavators in weight equivalent, which is proportional to the total bucket capacity of the manufactured excavators (Figure 1).

TABLE 1. Deliveries of excavators manufactured by UZTM-KARTEX Group

Manufactures and models	**Russian Fedration and CIS deliveries, pcs.**																**Total**
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
IZ-KARTEX names after P.G.Korobkov Ltd.																	
EKG-10	29	23	24	34	7	14	20	18	8	8	4	8	7	5	12	3	224
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EKG-18P/ 20К/ 20КМ					1	1	1	3	2	1		2	2	2	3	5	23
EKG-32R								1		1		1					3
TOTAL IZ-CARTEX:	30	24	29	40	11	22	32	29	22	14	10	16	21	30	34	24	388
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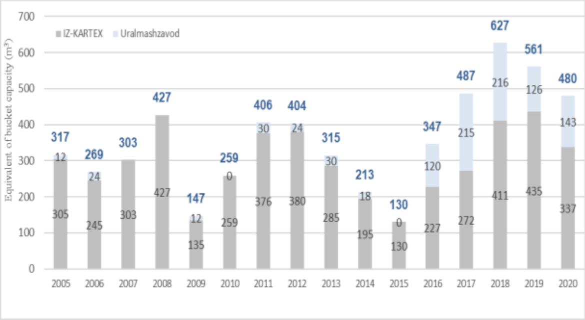

Figure 1. Dynamics of production of UZTM-KARTEKS mining excavators in equivalent of bucket capacity (m^3)

In terms of the equivalent total bucket capacity of excavators manufactured in the period from 2005 to 2020, the shares of the companies are: IZ-KARTEX - 83%, Uralmashzavod - 17%. In the period from 2016 to 2020, the share of excavators manufactured by Uralmashzavod increased to 31%.

In periog of 1970-2022, more than 250 mining excavators were delivered to the largest mining enterprises of Uzbekistan (Navoi Mining and Metallurgy Combinat, Almalyk MMC and Uzbekugol), of which 160 units are in operation today (5).

2. METHODS AND PROBLEM STATEMENT

Uzbekistan's enterprises are unique on a global scale:

- Almalyk MMC is the largest copper producer in Central Asia.
- Navoi MMC is one of the world's largest producers of gold and uranium and is among the world's top ten producers of both metals (6).

More than 90% of rock mass (Ore, Coal, and overburden) at mining enterprises of Uzbekistan is extracted by UZTM-KARTEX excavators. Excavator fleet (EKG) of the enterprises of Uzbekistan is presented in Table 2.

TABLE 2. Excavator fleet (EKG) of enterprises in Uzbekistan as of 2022

Mining enterprises	Raw materials	Model	Packs	Total
Navoi MMC	Gold	EKG-10	30	51
		EKG -15	15	
		EKG 20K	6	
Almalyk MMC	Copper	EKG 10	27	70
		EKG 15	28	
		EKG -20	15	
Uzbekcoal	Coal	EKG 10	26	39
		EKG 15	13	
TOTAL				160

There is also experience with the operation of open-pit hydraulic excavators by mining enterprises in Uzbekistan. As of 2022, in the period up to 2015, 1 unit of CAT 6030 with 15 m^3 bucket and Hitachi EX 3600 with 21 m^3 bucket were delivered to mining enterprises in Uzbekistan since 2017. There are 11 units of hydraulic excavators with 21–22 m^3 buckets of these, 8 Hitachi EX 3600 machines, 2 Komatsu PC 4000 machines, and 1 Caterpillar CAT 6040 machine.

In iron ore mining technology, open-pit hydraulic excavators are widely used for loading blasted mass in dump trucks. The working area of the excavator is characterized by a significant amount of iron ore fine dust in the air. In each working cycle, fines iron ore dust is deposited on the surfaces of hydraulic cylinder rods, hydraulic manipulator of the excavator, increasing the intensity of wear of rod surfaces and hydraulic cylinder seals. This process is typical for excavators operating in hot dry climate (7).

Increased dustiness of the working area can adversely affect the performance of excavator hydraulic cylinders. Operation of the equipment in dusty environment leads to the appearance of a static layer of iron ore dust on the surface of hydraulic cylinder rods. The properties of crushed bulk materials significantly depend on their disperse composition. Iron ore quartzites are quite contrasting in strength. The strength coefficient varies from 7.1 to 20.7 (8, 9).

According to ISO and the British Standards Institution (10, 11), dust is defined as fine solid particles, with a nominal diameter of less than 75 µm, that settle under their own weight but may remain suspended for some time. Dust particles from rock samples range in size from micrometres to 100 µm and are usually irregularly shaped (12). Figure 2 shows SEM image of iron ore dust partocles with irregular shapes.

Particle size, concentration and chemical composition are the most important properties of dust. Indicators such as PM_{10} (particles with aerodynamic diameter less than or equal to nominal 10 µm) and $PM_{2.5}$ (particles with aerodynamic diameter less than or equal to nominal 2.5 µm) are commonly used to determine standards and limits (13). In each working cycle of loading abrasive

TABLE 3. Results of X-ray spectral analysis of iron ore dust

Spectrum	Elements					Total, %
	Al	Si	Ca	Fe	O	
Spectrum 1		1.61	0.69	74.31	23.39	100
Spectrum 2	0.90	0.93		74.87	23.30	100
Spectrum 3				77.73	22.27	100

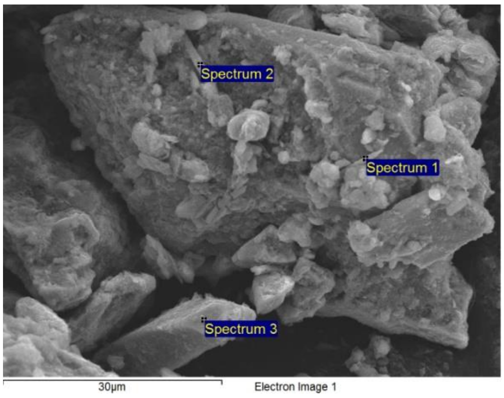

Figure 2. Scanning electron microscope images of iron ore dust particles

fine iron ore dust PM_{10} and $PM_{2,5}$ makes up 25% of the total fraction of iron ore dust in the air (35 $\mu g/m^3$); the dust settles on the surfaces of the rods of the power hydraulic cylinders of the excavator, causing an increase in the intensity of wear of the surface of the rods and seals of hydraulic cylinders. This process is typical for excavators operating in hot dry climate at temperatures above 40 °C (14).

3. DISCUSSION

For the development of cyclic-flow technologies (CFT) at the quarries of Uzbekistan, it is necessary to use mobile and mobile crushing units in technological schemes, which is especially characteristic for the development of low-abrasive rocks of medium strength.

The use of mobile crushing and transfer units (hereinafter referred to as MDPU) is possible with various technological schemes for open-pit mining of deposits. The MDPU should be placed in the face between the mining and loading machine and the face conveyor. As the excavator face moves, the MDPU moves along the work front (15, 16).

At the same time, establishing the optimal operating parameters of an excavator and other machines that are part of the mining and transport complex is a pressing issue. Many investigators have worked in this area, as their researches are reported in the literature (17).

4. SUGGESTIONS

The Angren open-pit coal mine is the prominent coal mining operation in Uzbekistan. The process of removing the top layer of the open-pit field in an open-pit mine is conducted using cyclic-flow technology, employing mobile crushing-loading-conveyor complexes (MCCC). The typical composition of MDPCC is shown in Figure 3 and consists of an excavation-loading machine (excavator of EKG type), crushing plant, interstage trans loader, and conveyor system. At the same time, following the technology, the crushing plant and the interstage loader are mobile machines.

The excavation of rock mass is carried out using an electric rope excavator EKG-15, which is produced by IZ-KARTEX. The rock mass is discharged into the mobile crusher via the hopper-feeder. Subsequently, the rock mass is transported from the mobile crushing plant to the downhole conveyor by means of the mobile conveyor-over loader. The justification for the utilization and effectiveness of mobile conveyor-over loaders is supported by the reduction in the frequency of downhole conveyor movements and the increased distance from the bottom hole when situated at the cutting location (18, 19).

Figuew 3 illustrates the technologies employed in executing mining operations inside a specific segment utilizing longitudinal stopes with MCCC. To execute this scheme, it is important to guarantee the appropriate positioning of the face conveyor laterally, as well as establish effective collaboration with a movable interstage loader. In this scenario, the mining activities are conducted in a sequential manner at two distinct horizons. Figure 4 illustrated the milling Milling of benches on two horizons using MCCC.

Within the context of this technical mining strategy, the downhole conveyor is positioned upon the top ledge. The intricate mechanism operates by initially engaging with the bottom ledge before subsequently transitioning to the higher ledge in a dual excursion. Subsequently, the gear undergoes linear motion along the anterior region of the excavation-loading apparatus.

Table 4 provides a comprehensive overview of the operational procedures involved in executing mining operations on a pull-out bench utilizing MCCC.

Aid The complete cycle of MCCC in accordance with the data of Table 4 under the condition of combining the operations of the technological process is presented in the form of the following experssion (14):

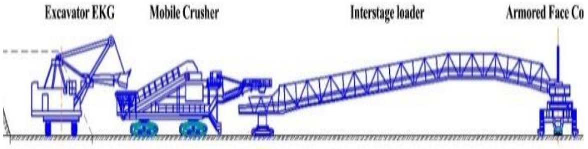

Figure 3. Typical composition of the MCCC

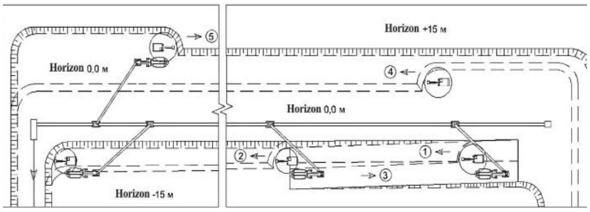

Figure 4. Milling of benches on two horizons using MCCC

TABLE 4. Operations of the technological process of mining operations at the off ramp using MCCC

Operation number	Operation name	Brief designation
1	Development of the first inclined exit ledge with descent to the lower horizon	$R_{sy(1)}$
2	Development of the left flank of the main lower ledge	$R_{oy(1l)}$
3	Turnaround and return movement of the complex on the left flank of the lower ledge.	$P_r + P_{oy(1l)}$
4	Development of the second inclined exit ledge	$R_{sy(2)}$
5	Moving the complex to the right flank of the lower ledge for turnaround and backward movement of the complex	$P_r + P_{oy(1p)}$
6	Moving the complex along the first inclined exit ledge to the upper horizon	$P_{sy(1)}$
7	Moving the complex to the initial position on the upper ledge	P_{ip}
8	Development of the first drift of the upper ledge	$R_{oy(2)}$
9	Development of the second drift of the upper ledge	$R_{oy(2')}$
10	Moving the complex on the turn to the first starting position	P'_{ip}
11	Moving the downhole conveyor	P_{zk}

$$1\ Cycle = \left[R_{sy(1)} + R_{sy(2)}\right] + \left[R_{oy(1l)} + R_{oy(2)} + R_{oy(2')}\right] + \left[P_r + P_{oy(1p)} + P_r + P_{oy(1p)} + P_{sy(1)} + P_{ip} + P'_{ip} + P_{zk}\right] = 2R_{sy} + R_{oy(1l)} + 2R_{oy(2)} + 2P_r + P_{oy(1)} + P_{sy(1)} + 2P_{ip} + P_{zk} \tag{1}$$

The time of one cycle of working of two ledges using MCCC is estimated as follows:

$$T_{Cycle} = 2T_{r.sy} + T_{r.oy(1l)} + 2T_{r.oy(2)} + 2T_{p.r} + 2T_{p.oy(1)} + T_{p.cy} + 2T_{p.ip} + T_{p.zk} \tag{2}$$

4. 1. Methodology for Determining Mining Time of an Inclined Exit Ledge and Productivity of MCCC

When extracting minerals from the deposit using a specific technological scheme that involves the MCCC as the destination, in combination with a mobile CBM for sequential mining on two horizons, it is crucial to consider all potential periods of inactivity of the mining and loading machine (20, 21). The predicted mining time of the exit ledge and the evaluated range of operating productivity of the MCCC were determined based on the proposed approach for the conditions of the Angren coal mine (22, 23). The technological specifications and starting statistics of the Angrensky coal mine face are presented in Table 5.

TABLE 5. Technological parameters of the Angrensky mine face

Name of process parameters	Designation	Unit.	Packs
Shoulder height	N_y	m	15
Slope angle of the ledge	α	degree	70
Excavator approach width	V_z	m	22.5-25
Distance from the bottom edge of the scarp to the crusher transportation line	s_1	m	1.2-4.05
Installation width of the interstage transloader	$V_{y,m,p}$	m	20-90
Width from the conveyor axis to the upper edge of the bottom ledge	$V_{k,y,}$	m	10
Working platform width	$V_{r,p}$	m	60-130
Angle of excavator rotation on unloading	β	degree	60-180
Soil type: sandstones and gravels in clayey cement			
Density	γ	t/m^3	1.9-2.3
Loosening factor	k_r	-	1.1-1.4

According to the requirements of operational documentation, the operation of open-pit rope excavators is allowed with an angle of up to 5°. This requirement is retained in MCCC technology when driving the exit ledges, but additional restrictions are imposed on the rest of the equipment of the complex. The scheme of the exit ledge with the main parameters is presented in Figure 5.

The limit angle of the exit ledge is determined from the ratio 1:20. At 5% slope the angle will be equal to 2.86°. At the height of the ledge accepted at Angren coal mine equal to 15 m, the length of the exit ramp will be 300.6 m. The average statistical distance of excavator EKG-15 excavator movement during the sinking of the exit ledge is 4 m, so the number of excavator movements during the mining of the exit ledge length of 300.6 m is 75. The exit ledge is divided into 75 sections, each of which is equal to one excavator travel of the excavator EKG-15.

During the early phase of the operation, the EKG excavator is unable to achieve the designated load capacity for the crushing plant because of the incomplete filling of its bucket. The observation pertains to a distinctive characteristic exhibited by excavators of the

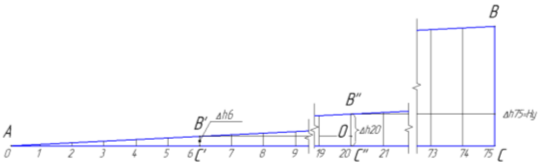

Figure 5. Calculation scheme of the exit ramp

EKG classification, specifically in relation to their excavation path. To ensure the efficient functioning of the excavator, it is necessary to determine the optimal height at which the rock mass should be picked, taking into consideration the maximum capacity of the excavator bucket (24-26).

To determine the length of the excavator's digging arc when the bucket is filled to its full capacity, the calculation relies on many key data points. These include the depth at which the bucket penetrates the rock mass (also known as chip thickness), the geometric characteristics of the bucket, and the physical and mechanical qualities of the rock mass. Hence, the magnitude of the excavation arc is ascertained using the given mathematical expression:

$$L_{D,h} = \frac{V_k K_n}{W_k S_{max} K_r} \quad (3)$$

where V_k – excavator bucket volume, m^3,

K_n – bucket fill factor,

K_r – loosening factor,

W_k – bucket width, м,

S_{max}– maximum embedding depth (maximum chip thickness), m,

$S_{ch,th,}$– current embedding depth (current chip thickness), m,

The depth of bucket penetration into the rock mass mass is determined by calculations, which take into account the static loads arising during exaction, as well as reference data - specific resistance to digging of rock mass [30, 32]:

$$S_{max} = \frac{R_k}{K_f W_k}, \quad (4)$$

where R_k – digging force, N.

k_f – specific resistance to digging, N/m^2.

The calculation of digging force involves considering various factors such as the mass and dimensions of all components of the excavator bucket, the volume and specific weight of the rock contained in the bucket, and the locking force exerted by the lifting and head drives. This force is determined by applying an equal force on the teeth of the bucket and is calculated based on specific operating conditions using the experssion.

Based on the shown diagram of the escape ledge (Figure 5), it can be observed that EKG-15 is engaged in excavation activities up to sub-block 6. The excavation process involves the utilization of a rock mass established at the standing level, whereby the bucket filling operation is performed in a horizontal plane. In relation to the matter of productivity, the excavation cycle time in sections up to the sixth is determined, and the value of K_n is established in line with Table 6 (27-29).

n - turn of excavator sub-block separation; ΔV1 - rock volume of the first sub-block, m^3

In accordance with the data of the table "Main technological parameters of the exit scarp mining" the dependence of the bucket filling ratio on the volume of excavated sub-block can be traced (Figure 6).

The time of sub-block development from the beginning of excavation to sub-block six, taking into account the movement of the complex, is obtained from the following expression:

$$t_{0-6} = 6t_{cycle}\frac{W_z}{V_k} + \frac{l_{0-6}}{L_{front}} t_{front} \quad (5)$$

where t_{cycle} – excavation cycle time, s,

W_z – excavator headway width, m,

L_{0-6} – length of the sub-block, m,

L_{front} – distance of one movement of the complex, m,

t_{front} – time of one move of the complex, min.

Average productivity of the complex when mining sub-blocks up to the sixth one:

$$Q_{sr(0-6)} = \frac{60 \cdot V_{0-6}}{t_{0-6}} \quad (6)$$

where V_{0-6} – volume of rock mass of sub-block 0-6, m^3,

t_{0-6} – sinking time of sub-block 0-6, min.

Further, in the process of mining the exit ledge from the sixth sub-block, the height of the face will gradually increase from 1.2 m to the maximum value, in this case

TABLE 6. Basic technological parameters of the scarp mining

Parameters	Calculation formulas	1-sub-block	2-sub-block	3-sub-block
Volume of rock of one scooping, m^3	ΔVn=(2n–1) ΔV1	1.5	4.5	7.5
		4-sub-block	**5-sub-block**	**6-sub-block**
		10.5	13.5	16.5
Bucket filling factor	$К_н=(\Delta Vn/Vк)$	**1-sub-block**	**2-sub-block**	**3-sub-block**
		0.09	0.27	0.45
		4-sub-block	**5-sub-block**	**6-sub-block**
		0.64	0.82	1.00

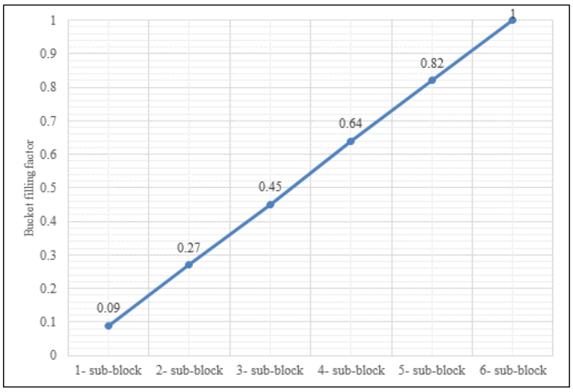

Figure 6. Changing the bucket filling factor from the volume of the sub-block

the bucket filling factor will be equal to 1. Up to the fifth sub-block inclusive bucket filling EKG-15 occurs in the horizontal plane is analogous to the process of picking up rock mass front loader. From the sixth sub-block and further the trajectory of digging is an arc determined by the excavator arm outreach. In this case the excavator will work with the permissible depth of bucket penetration into the face (permissible chip thickness) (22, 23).

In order to determine the actual productivity of EKG-15 when driving the exit ledge, it is necessary to take into account all the conditions of this face. The efficiency of mining and loading equipment operation is evaluated by productivity, which in turn is determined by the excavation cycle time. In order to optimize the excavation cycle and bring it closer to the nominal parameters, it is necessary to work with the set digging height. The rational height of rock mass set by the excavation and loading machine is determined by the condition of its bucket filling when developing the exit ledge. Bucket filling factor at the set depth of bucket penetration into the face is estimated by the expression:

$$K_z = \frac{W_k S_{max} \, L_{d,h}}{V_k} = \frac{W_k S_{scoop}}{V_k} \tag{7}$$

where S_{scoop} – cross-sectional area of one scoop at known chip thickness, m^2.

The determination of the excavator bucket fill factor is conducted for various face heights, as outlined in the schematic diagram provided in Figure 6. The rise in facial height leads to an elevation in the digging trajectory, while simultaneously preserving the depth of bucket penetration into the face and, consequently, the quantity of excavated rock mass every cycle (24-26).

In the assessment of the lower surface, it is imperative to utilize a mathematical model to ascertain the excavator's digging area, specifically the ring sector. This calculation should consider the depth of the bucket's penetration into the massif, as illustrated in Figure 7.

The area described by the points OABC is calculated in a rectangular coordinate system. The Oh axis is drawn through the segment OA, and the Ou axis is drawn at the point O perpendicular to the Oh axis. Thus, the sought area OABC is bounded by the lines.

$$x^2 + (y - 8{,}5)^2 = 8{,}5^2,\ x^2 + (y - 8{,}5)^2 = 9{,}5^2,$$
$$y = 0 \quad y = a$$

Or (8)

$$x = \sqrt{8{,}5^2 - (y - 8{,}5)^2},\ x = \sqrt{9{,}5^2 - (y - 8{,}5)^2},$$
$$0 \le y \le a.$$

Then the required area is calculated using the double integral:

$$S = \iint\limits_{OABC} dxdy = \int_0^{\Delta h} \left[\int_{\sqrt{R_1 - (y - R_1)^2}}^{\sqrt{R_2 - (y - R_1)^2}} dx \right] dy = \int_0^{a} \left[x \Big|_{\sqrt{{R_1}^2 - (y - R_1)^2}}^{\sqrt{{R_2}^2 - (y - R_1)^2}} \right] dy \tag{9}$$

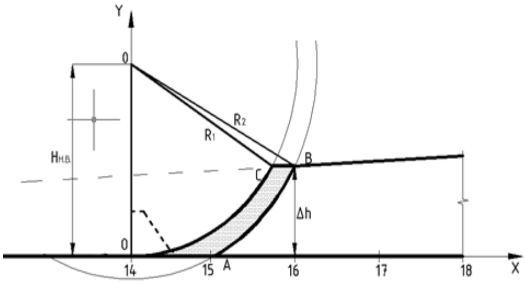

Figure 7. Calculation scheme for determining the area of the excavator digging segment

By setting a number of values Δh_y and S_{max} the corresponding values of the OABS(S_{scoop}) area and, respectively, the volume of excavated rock mass (V_p), as well as the bucket filling factor K_z are determined. According to the graph of the function $K_z = f(\Delta h_y)$, the specific values of the bucket filling factor of the excavator bucket are determined (Figure 8).

The results of the calculations for establishing the excavator bucket fill factor during the formation of the exit scarp (21, 30, 31) are presented in Table 7.

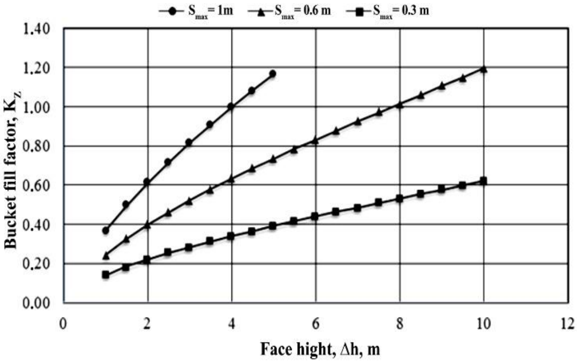

Figure 8. Excavator bucket filling ratio from the excavator face height when changing the penetration depth

TABLE 7. Parameters of the scarp and bucket fill factor

Δh, m	S_{max}, m	R_1, m	R_2, m	S_2, m^2	V_p, m^3	V_k, м^3	K_n
1,0	1	8,5	9,5	2,42	6,06	16,5	0,37
1,5	1	8,5	9,5	3,28	8,19	16,5	0,50
2,0	1	8,5	9,5	4,04	10,09	16,5	0,61
2,5	1	8,5	9,5	4,74	11,84	16,5	0,72
3,0	1	8,5	9,5	5,39	13,47	16,5	0,82
3,5	1	8,5	9,5	6,00	15,01	16,5	0,91
4,0	1	8,5	9,5	6,59	16,48	16,5	1,00
4,5	1	8,5	9,5	7,16	17,90	16,5	1,08
5,0	1	8,5	9,5	7,71	19,28	16,5	1,17

To fill the bucket with a cap in accordance with GOST R 55165-2012, the excavator at one digging run has a minimum required face height of 4m. Thus, up to the twentieth sub-block the excavator operates in the mode of reduced productivity (24-26). From the twenty-first sub-block the excavator switches to nominal operation mode.

Subblock working time $(n-(n+1))$ is determined by the expression:

$$t_{n-(n+1)} = \left(\frac{L_{n-(n+1)}}{S_{ch,th,}} \cdot t_{cycle}\right) \cdot \frac{V_z}{V_k} + \frac{L_{n-(n+1)}}{L_{front}} \cdot t_{front} \quad (10)$$

The volume of sub-block $(n-(n+1))$ is determined by the expression:

$$V_{n-(n+1)} = \left(\frac{L_{n-(n+1)} \cdot (\Delta h_{(n+1)} - \Delta h_n)}{2} \cdot V_z\right) + \left(L_{n-(n+1)} \cdot \Delta h_n \cdot V_z\right) \quad (11)$$

Average productivity of the sub-block mining complex $(n-(n+1))$:

$$Q_{sr(n-(n+1)} = \frac{60 \cdot V_{n-(n+1)}}{t_{n-(n+1)}} \quad (12)$$

5. CONCLUSION

This research entailed the formulation of a systematic approach and a mathematical framework to effectively assess the duration of operation for an inclined exit ledge and forecast the efficiency of Mobile Conveyor Crushing Complex (MCCC) under the specific circumstances prevailing at the Angren coal mine, Angrensky. The objective of this study was to enhance the efficacy of the mining procedure. The primary focus of this study pertained to the specific conditions of the Angren coal mine. The present study will be conducted at the Angren coal mine, with the primary aim of identifying strategies that can enhance the productivity of mining operations at this site.

6. AUTHORS' CONTRIBUTION

Annakulov T.J. - generating the idea of the study, setting the research problem.
Shibanov D.A. - performing work on systematization of material; conducting data analysis and creating tables and figures; writing the text of the article.
Abdelvahab Agagena - performing experimental studies, obtaining data for analysis, assisting in translating the text; writing the text of the article.

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Persian Abstract

چکیده

این مقاله داده هایی را در مورد ناوگان تکنولوژیکی اصلی تجهیزات بارگیری حفاری شرکت های معدنی ازبکستان ارائه می دهد که به طور سنتی مصرف کننده بیل های طناب روباز از نوع ECG هستند. ازبکستان که به طور سنتی مصرف کننده بیل های طناب روباز از نوع ECG هستند. اطلاعات مربوط به تجربه بهره برداری از بیل های هیدرولیک روباز توسط شرکت های معدنی ازبکستان تا سال ۲۰۲۲ ارائه شده است. روش تعیین زمان کار و بهره وری بیل مکانیکی در توسعه طاقچه خروجی شیبدار در شرایط معدن زغال سنگ Angrensky (ازبکستان) ارائه شده است. محاسبه زمان کار طاقچه خروجی انجام می شود و میانگین بهره وری عملیاتی بیل مکانیکی تعیین می شود. فن آوری استخراج طاقچه با رانش های طولی با استفاده از مجتمع های سنگ شکن بیل متحرک در محل جانبی نوار نقاله پایین سوراخ و حضور یک لودر متحرک بین مرحله ای با عملیات استخراج متوالی در دو افق ارائه شده است. با توجه به طرح فن آوری داده شده، روش تعیین چرخه کاری کامل مجموعه توصیه می شود. تخمین ضریب پر شدن سطل بیل مکانیکی در ارتفاعات مختلف و عمق نفوذ سطل مختلف به داخل صورت انجام می شود. یک مدل ریاضی برای تعیین مساحت بخش حفاری یک بیل مکانیکی معدن توسعه داده شده است. مدل ریاضی تعریف مساحت حجم گودبرداری برای یک سیکل حفاری منفرد با در نظر گرفتن عمق نفوذ سطل به سطح برای تخمین دقیق پارامترهای صورت پیشنهاد شده است.