

Mathematical Modeling of Determining the Productivity of Mobile Complexes in Exercise of Inclined Connecting Accessories

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ABSTRACT

This article provides a methodology for determining the working time and productivity of mobile excavator-crushing and conveyor complexes in the development of an inclined exit ledge. At different bottom heights, the fill factor of the excavator bucket is determined. A mathematical model has been developed to determine the area of the excavator digging segment with the establishment of the chip thickness.

Keywords: excavator-crushing complex, excavator productivity, inclined exit bench, working time, double integral.

1.INTRODUCTION

Currently, in the development of overburden of coal

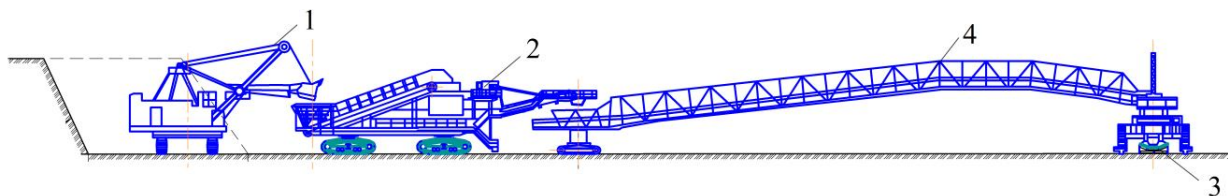


Figure 1: The technological scheme of working out the ledge using a mobile excavator and conveyor complex: 1 - excavator; 2 - mobile crushing plant; 3 - downhole conveyor belt; 4 - mobile conveyor loader

Let us consider the technological scheme for working out benches with longitudinal runs by the MCRCC complex with a lateral location of the downhole conveyor and the presence of a mobile interstage loading crane with sequential mining operations at two horizons (see Figure 2). According to this technological scheme, the MCRCC system works on two horizons. In this case, the

downhole conveyor is installed on the upper ledge. Excavator-mobile crusher - an interstage reloader works first on the lower ledge, and then on the upper ledge with two runs. After that, the downhole conveyor moves along the front of the excavator [5,9,11].

The technological processes during mining operations on the exit ledge using MCRCC are shown in the table. 1.

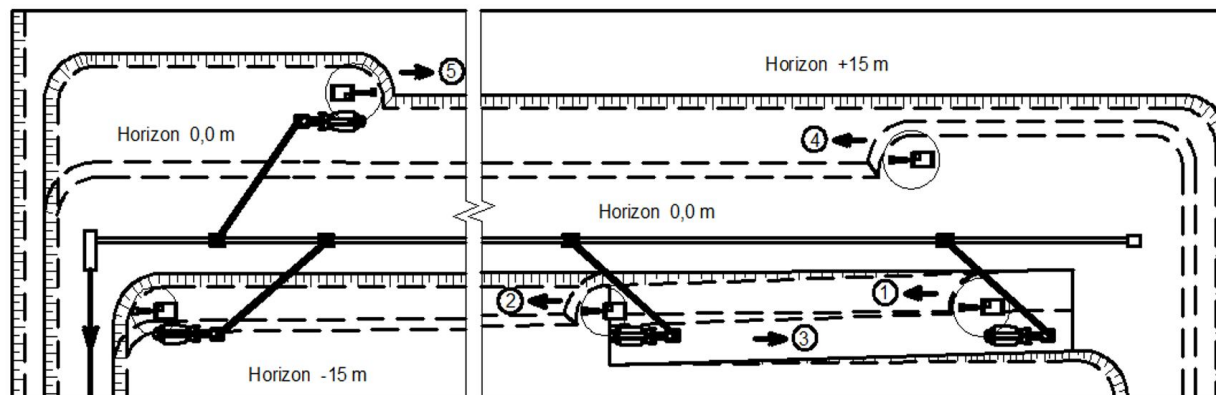


Figure 2: The technological scheme of working out benches using mobile systems with sequential mining operations at two horizons [11]

Table 1:Technological processes of mining with a ramp using MCRCC

Process number	Process name	Process Brief
1	Development of the first inclined exit ledge with the descent to the lower horizon	R _{EL(1)}
2	Development of the left flank of the main lower ledge	R _{ML(1L)}
3	U-turn and reverse movement of the complex on the left flank of the lower ledge	D _T +D _{ML(1L)}
4	Development of a second inclined exit ledge	R _{EL(2)}
5	U-turn and reverse movement of the complex along the right flank of the lower ledge	D _T +D _{ML(1R)}
6	Moving the complex along the first inclined exit ledge to the upper horizon	D _{EL(1)}
7	Moving the complex to its starting position on the upper ledge	D _{SP(2)}
8	Development of the first entry of the upper ledge	R _{ML(1E)}
9	Development of the second entry of the upper ledge	R _{ML(2E)}
10	Movement of the complex by turning to the first starting position	D _{SP(1)}
11	Downhole conveyor movement	D _C

According to the table. 1, combining the relevant processes, we determine the full cycle of MCRCC in the following form [5]:

$$1 \text{ CYCLE} = [R_{EL(1)} + R_{EL(2)}] + [R_{ML(1L)} + R_{ML(1E)} + R_{ML(2E)}] + [D_T + D_{ML(1L)} + D_T + D_{ML(1R)} + D_{EL(1)} + D_{SP(2)} + D_{SP(1)} + D_C] = 2R_{EL} + R_{ML(1L)} + 2R_{ML(2)} + 2D_T + D_{ML(1)} + D_{EL(1)} + 2D_{SP} + D_C(1)$$

The time of one cycle of working out of two benches with the use of MCRCC is [5]:

$$T_{CYCLE} = 2T_{R,EL} + T_{R,ML(1L)} + 2T_{R,ML(2)} + 2T_{D,T} + T_{D,ML(1)} + T_{D,EL(1)} + 2T_{D,SP} + T_{D,C}, h \quad (2)$$

2. METHODOLOGY FOR DETERMINING THE WORKING TIME OF AN INCLINED EXIT LEDGE AND THE PRODUCTIVITY OF THE MCRCC COMPLEX

When calculating the operational productivity and operating time of the complex according to the technological scheme for the development of rocks with an end position of the MCRCC and the presence of a mobile interstage loading crane with sequential mining at two

horizons, all downtimes of the excavator must be taken into account.

We calculate the working time of the exit ledge and determine the average operational productivity of the MCRCC complex in the conditions of the Angrencoal mine [10].

Initial data for the calculation: Existing technological parameters of the face of the Angrensky section and the initial data are summarized in the table. 2, and the technical characteristics of the excavator, crusher and mobile interstage conveyor loader - in the table 3.-5.

Table 2: Existing technological parameters of the face

Name of technological parameters	Symbol	Measurement	Quantity
Ledge height	H _L	m	15
Ledge angle	α	grad.	70
Excavation trench width	B _W	m	22,5-25
Distance from the bottom edge of the ledge to the crusher transport line	c ₁	m	1,2-4,05
Installation width	B _{I,W}	m	20-90
Width from conveyor axis to the upper edge of the lower ledge	B _{L,L}	m	10
Platform width	B _{P,W}	m	60-130
Unloading angle of the excavator	β	grad.	60-180
Soil type: sandstones and pebbles in clay cement			
Density	γ	t/m ³	1,9-2,3
Coefficient of loosening	k _L		1,1-1,4

Table 3: Technical characteristics of the excavator EKG-15M

Basic operating parameters	Sym-bol	Measure-ment	Quan-tity
Bucket capacity	V _b	m ³	16,5
Standing level scooping radius (maximum)	R _{CT} ^{max}	m	15,6
Standing level scooping radius (minimum)	R _{CT} ^{min}	m	10,1
The greatest radius of scooping	R _q ^{max}	m	22,6
Greatest heights	H _G ^{max}	m	15,8
Highest discharge height	H _{B,B} ^{max}	m	9,9
The largest radius of unloading	R _U ^{max}	m	19,5
Cycle duration (at 900)	t _c	s/min	28/0,46
Excavator head height	H _{head}	m	18,7
Excavator height on biped rack	H _{biped}	m	15,0
Travelspeed	V _{travel}	km/h	0,72

Table 4: Technical specifications of mobile crusher

Basicoperatingpara-meters	Sym-bol	Measure-ment	Quan-tity
Estimated productivity	P _E	t/h	4000
Crushedrockfortress	f		8-12
Hoppercapacity	V _H	m ³	50

Hopper height	H_H	m	8
Boom length	L_{BL}	m	18-25
Totallengthofcrusher	L_C	m	44
Crusher width	B_C	m	12,8
The size of the loaded material: 1100 mm (5% of the total mass), over 300 mm (20% of the total mass), up to 300 mm (75% of the total mass)			
Final material fineness		mm	0-300

Table 5: Technical specifications of mobile interstage conveyor loader

Basicoperatingparameters	Sym-bol	Measure-ment	Quan-tity
EstimatedProductivity	P_E	t/h	4000
Feedsizes	d	mm	0-300
The height of the worked benches	H_h	m	15

The total length of the rece-iving and unloading boom	L_b	m	72-82
Tiltboom		grad.	± 16
Tippingboom		grad.	± 16
TravelSpeed (Maximum)	$V_{пер}$	m/min	8-10
Minimumturningradius	R_P^{min}	m	10-12
Allowedtiltwhenmoving	i_a		1:10
Permissibleiltlduringoper-ation	i_p		1:20

When working out an exit ledge with the use of MCRCC, up to 5% slope is allowed, which has the form shown in Figure 3. The permissible angle of the inclination of the ramp is equal to a ratio of 1:20. With a 5% slope, this angle will be 2.86° .

Define the length of the ramp on the segment AB with the height of the ledge 15 m: $AB=BC/\sin 2,86^\circ=300,6$ m.

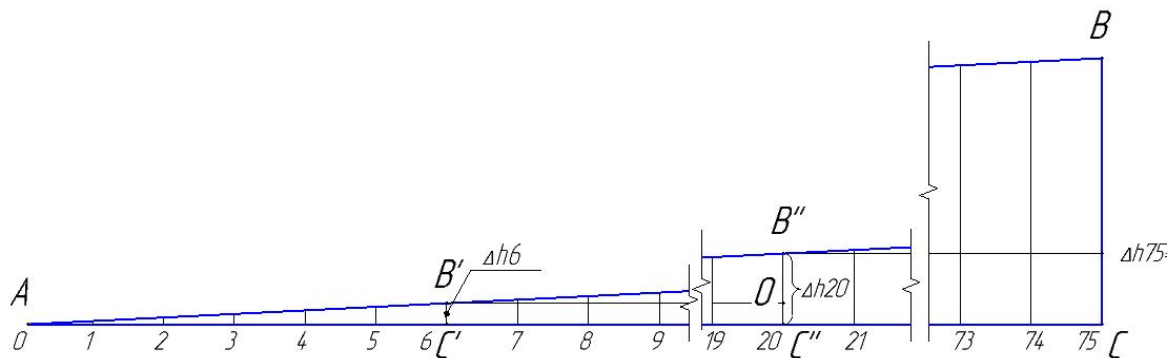


Figure 3: The scheme of the exit ledge with the division into 75 subunits of length, each equal to one excavator, moving

Taking into account the movement of the excavator from one parking lot to the next with $L_{moving} = 4$ m, the number of subunits will be $300,6 / 4 = 75$. This means that the excavator, working on the exit ledge, moves 75 times (Fig. 3).

In the first part of the block, the excavator will not be able to load the crushing plant due to the non-filling of its bucket. In this regard, under the conditions of the effective operation of the excavator, we determine the minimum digging height.

Under the conditions of full filling of the bucket with a known thickness of the removed chips, we determine the length of the scooping arc:

$$l_{d.s.} = \frac{V_b k_f}{B_b C_{max} K_L}, \text{ m} \tag{3}$$

where B_b - is the width of the excavator bucket, m;
 C_{max} - the thickness of the removed chips, m;
 k_f - bucket fill factor;

The thickness of the removed chips is determined by calculations, taking into account the digging force of the excavator and the specific resistance to digging the rock [6]:

$$C_{max} = \frac{P_t}{k_S B_b}, \text{ m} \tag{4}$$

where P_t - is the force on the teeth of the bucket of the excavator, N;

k_S - specific resistance to digging rocks, N/m^2 .

Digging resistivity for rocks of category III is accepted for excavator $k_F = 160 \div 280 \text{ kPa} = (16 \div 28) \cdot 10^4, N/m^2$ [7].

The force on the teeth of the excavator bucket for specific conditions of the face is determined by the formula [8]:

$$P_{t.b} = \frac{N_r \cdot l_{h.c} + G_{(b+br)} \cdot l_{h.b} + G_p \cdot l_{h.h}}{l_h}, \text{ N} \tag{5}$$

where N_r - resistance to rock digging, N;

$G_{(b+br)}$ - the weight of the bucket with the breed, N;

G_h - handle the weight, N;

$l_{h.c}$, $l_{h.b}$, $l_{h.h}$ - respectively, the length of the handle from the pressure shaft to the bottom contact, to the center of gravity of the bucket and the center of gravity of the handle, m.

The resistance of the breed to digging is determined by the formula [8]:

$$N_r = \frac{k_S E}{H_{p.sh} \cdot k_l}, \text{ N} \tag{6}$$

where $H_{p.sh}$ - is the height of the pressure shaft, m;

k_l - coefficient of loosening of the rock, $k_l = 1,2-1,3$.

In the face pattern shown in Fig. 3, it can be seen that the excavator, until subunit 6, works with horizontal scooping at a standing level. In this case, the volume of the rock, the

working time of subunits 0-6 and the filling factor of the excavator bucket is determined according to the table. 6.

Table 6: Determination of technological parameters for working out of exit ledges

Parameters	Calculation formulas	1-subunit	2-subunit	3-subunit	4-subunit	5-subunit	6-subunit
Rock volume of one digging, m ³	$\Delta V_n = (2n - 1)\Delta V_1$	1,5	4,5	7,5	10,5	13,5	16,5
Sub block processing time, s	$\Delta t_n = (B_w/B_b)t_c$	180	180	180	180	180	180
Bucket fill factor	$k_f = \left(\frac{\Delta V_n}{V_b}\right)$	0,09	0,27	0,45	0,64	0,82	1,00

*n - is the separation queue of the excavator subunit; ΔV_1 - rock volume of the first subunit, m³; B_b - excavator bucket width, m.

According to the data given in the table. 6, we establish the dependence of the fill factor of the bucket of the excavator on the removable volume of the subunit.

From fig. 4 shows that the excavator to subunit 6 works with horizontal scooping at a standing level and minimum bucket filling factors.

The working time of subunits 0-6, taking into account the movement of the complex will be:

$$t_{0-6} = 6 \cdot t_c \cdot \frac{B_w}{B_b} + \frac{L_{0-6}}{L_m} \cdot t_m, h \quad (7)$$

where t_m -the time of one movement of the complex, min.

The average productivity of the complex when practicing subunits 0-6:

$$Q_{s(0-6)} = \frac{60 \cdot V_{0-6}}{t_{0-6}}, m^3/h \quad (8)$$

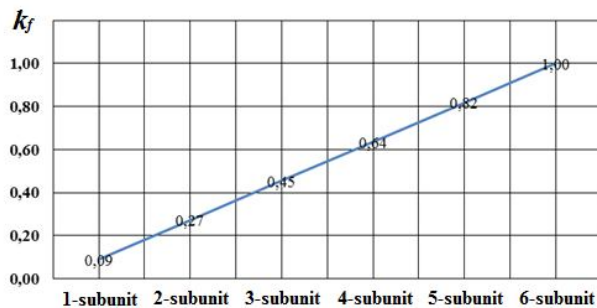


Figure 4: The dependence of the fill factor of the bucket of the excavator on the removable volume of the subunit

Starting from subunit 6, the bucket filling ratio will be equal to 1, while the bottomhole height will be 1.2 m and will be higher than the chip thickness. In this regard, the excavator will not be able to scoop in horizontal layers and will begin scooping along the radius of the handle with an allowable chip thickness.

In this case, it is necessary to determine the actual performance of the excavator, taking into account the conditions of the face. The effective operation of the excavator is determined by establishing the height of the digging. Therefore, the sufficient height of the digging of the excavator is determined from the conditions of filling its bucket when developing a ramp. The formula determines the bucket filling factor with the installed chip thickness:

$$k_f = \frac{B_b C_{max} l_a}{V_b} = \frac{B_b S_{c.s.}}{V_b}, \quad (9)$$

where l_a - is the arc of digging, m;

$S_{c.s.}$ - is the cross-sectional area of one scooping with a known chip thickness, m².

For different bottom heights, we determine the fill factor of the excavator bucket according to the scheme shown in Fig. 5. It can be seen from the diagram that with an increase in the bottom height, the length of the scooping arc increases and, accordingly, the volume of rock per scoop.

For a more accurate calculation of the face, we use the mathematical model for determining the area of the excavator's digging segment with the establishment of chip thickness (with radii scooping R_1 and R_2) (Figure 5).

To calculate the OABC area, we construct a rectangular coordinate system. We draw the OX axis through the segment OA and the OY axis at the point O perpendicular to the OX axis. Then the desired region of OABS is limited by lines

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

or

$$x = \sqrt{8,5^2 - (y - 8,5)^2}, \quad x = \sqrt{9,5^2 - (y - 8,5)^2}, \\ 0 \leq y \leq a. \quad (10)$$

Then the desired area is calculated using the double integral:

$$S = \iint_{OABC} dx dy = \int_0^{\Delta h} \left[\int_{\sqrt{R_1^2 - (y - R_1)^2}}^{\sqrt{R_2^2 - (y - R_1)^2}} dx \right] dy = \\ = \int_0^{\Delta h} \left[x \Big|_{\sqrt{R_1^2 - (y - R_1)^2}}^{\sqrt{R_2^2 - (y - R_1)^2}} \right] dy = \\ = \int_0^{\Delta h} \left(\sqrt{R_2^2 - (y - R_1)^2} - \sqrt{R_1^2 - (y - R_1)^2} \right) dy = \\ = \left[\begin{matrix} t = y - R_1, dt = dy \\ y = 0, t = -R_1 \\ y = \Delta h, t = \Delta h - R_1 \end{matrix} \right] =$$

$$\begin{aligned}
 &= \int_{-R_1}^{\Delta h - R_1} \left[\sqrt{R_2^2 - t^2} - \sqrt{R_1^2 - t^2} \right] dt = \int_{-R_1}^{\Delta h - R_1} \sqrt{R_2^2 - t^2} dt \\
 &\quad - \int_{-R_1}^{\Delta h - R_1} \sqrt{R_1^2 - t^2} dt = \\
 &= \frac{1}{2} \left(t \sqrt{R_2^2 - t^2} + R_2^2 \arcsin \frac{t}{R_2} \right) \Big|_0^{\Delta h} \\
 &\quad - \frac{1}{2} \left(t \sqrt{R_1^2 - t^2} + R_1^2 \arcsin \frac{t}{R_1} \right) \Big|_0^{\Delta h} = \\
 &= \frac{1}{2} \left((\Delta h - R_1) \sqrt{R_2^2 - (\Delta h - R_1)^2} + R_2^2 \arcsin \frac{\Delta h - R_1}{R_2} \right. \\
 &\quad \left. + R_1 \sqrt{R_2^2 - R_1^2} + R_2^2 \arcsin \frac{R_1}{R_2} \right) - \\
 &- \frac{1}{2} \left((\Delta h - R_1) \sqrt{R_1^2 - (\Delta h - R_1)^2} + R_1^2 \arcsin \frac{\Delta h - R_1}{R_1} \right. \\
 &\quad \left. + R_1^2 \frac{\pi}{2} \right) = \tag{11}
 \end{aligned}$$

3. RESULTS

By asking several values Δh and C_{max} , we find the corresponding values of the OABS area ($S_{c.s}$) and, accordingly, the removed rock volume (V_n), as well as the bucket, fill factor k_f . According to the graph of the function $k_f = f(\Delta h)$, determine the specific values of the filling coefficient of the excavator bucket Figure 6. In the table 7 shows the results of calculations to determine the fill factor of the bucket of the excavator during the development of the exit ledge.

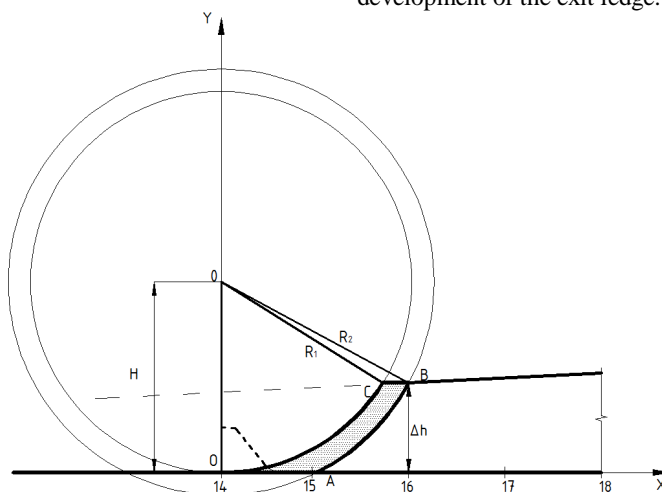


Figure 5: Scheme for determining the area of the excavator's digging segment when developing an exit ledge with establishing chip thickness: H - excavator pressure shaft height.

Table 7: The results of the calculation of determining the fill factor of the bucket of the excavator during the development of the exit ledge

$\Delta h, m$	C_{max}, m	R_1, m	R_2, m	$S_{c.s.}, m^2$	V_s, m^3	V_b, m^3	k_f
1,0	1	9,5	8,5	2,42	6,06	16,5	0,37
1,5	1	9,5	8,5	3,28	8,19	16,5	0,50
2,0	1	9,5	8,5	4,04	10,09	16,5	0,61
2,5	1	9,5	8,5	4,74	11,84	16,5	0,72
3,0	1	9,5	8,5	5,39	13,47	16,5	0,82
3,5	1	9,5	8,5	6,00	15,01	16,5	0,91
4,0	1	9,5	8,5	6,59	16,48	16,5	1,00
4,5	1	9,5	8,5	7,16	17,90	16,5	1,08
5,0	1	9,5	8,5	7,71	19,28	16,5	1,17

From the table 7 it is seen that to fill the excavator bucket with one scooping, the required bottomhole height will be $\Delta h = 4$ m. This means that until the subunit 20, the

excavator will operate with lower productivity. After the 20th subunit, the excavator will begin to work as usual.

The expression determines the processing time of the subblock (n- (n + 1)):

$$t_{(n-(n+1))} = \left(\frac{L_{(n-(n+1))}}{C_{ch}} \cdot t_c \right) \cdot \frac{B_w}{B_b} + \frac{L_{(n-(n+1))}}{L_m} \cdot t_m, \text{ h} \quad (12)$$

where C_{ch} - the thickness of the removed chips, m.

The expression determines the volume of the subblock (n- (n + 1)):

$$V_{(n-(n+1))} = \left(\frac{L_{(n-(n+1))}(\Delta h_{(n+1)} - \Delta h_n)}{2} \cdot B_w \right) + (L_{(n-(n+1))} \cdot \Delta h_n \cdot B_w), \text{ m}^3 \quad (13)$$

The average productivity of the sub-block mining complex (n- (n + 1)):

$$Q_{av(n-(n+1))} = \frac{V_{(n-(n+1))}}{t_{(n-(n+1))}}, \text{ m}^3/\text{h}; \quad (14)$$

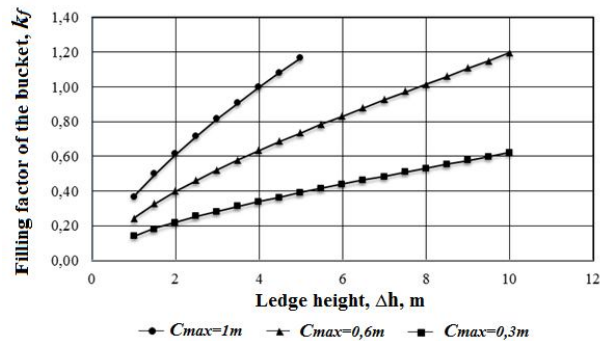


Figure 6. The dependence of the filling factor of the bucket of the excavator on the height of the bottom at different chip thickness

4. CONCLUSION

Thus, a methodology and mathematical model have been developed for determining the working time and productivity of the mobile crushing, reloading and conveyor complexes when working out an inclined exit ledge

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