Research Regarding the Establishment of Force and Energetic Characteristics of the Bucket Wheel Excavator in given Working Conditions

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Abstract: - This paper presents the power and energy characteristics whit the view to defining and analyzing the working mode of the rotor excavators in operation at Oltenia lignite open casts, for lignite mining and for mining of the predominantly overburden rock, i.e. the sandy clay. The forces which act on a bucket and wheel, the force needed for the excavation and for lifting the material, as well as the force necessary for turning around the superior platform of the excavator during operation will be calculated. The calculus method applies to bucket wheel excavators type EsRc 1400 and SRs 1300. A software for the study of force and energetic excavation parameters is presented.

Key-Words: Rotor excavator, Working mode, Forces, Power, Power consumption, Excavation capacity, Case study, Software

1. Generals

The following parameters range among the basic operating parameters of the rotor excavators: the power necessary for motor driving; the excavation capacity and the specific power consumption, the power necessary to cut the removed material and the power necessary to lift up the loose material with the help of buckets for their further removal and discharge. Among these two components, the basic one is the cutting power that represents between 60 and 90% of the power necessary to drive on the rotor. It is utterly important to know the power for given working conditions if you want an increased efficiency of the mechanized cutting, both from the power consumption point of view and from the point of view of the cutting capacity, i.e. the final output.

Finding this parameter in relation to the excavating capacity and the specific power consumption shall lead to a better identification of the working mode of the excavator for certain given conditions and represent an essential element both in the selection of excavator from an existing batch and for the design of new excavators or new cutting - loading systems for the current excavators, with the consideration of the future working conditions for these equipment.

The determination of the installed power necessary for a mechanized cutting with the help of rotor excavators calls for the following determinations:

- the relation between the power of an given excavator and the parameters of the working mode for this excavator;
- the power necessary to work in an efficient mode, i.e. a good cutting capacity with minimum power consumption;
- the relation between the power adsorbed by the engine (the engines) of the cutting – loading system and the cutting capacity and the swiveling speed at the working place.

Consequently, there follows an analysis of the above mentioned aspects so that the calculation relation which are going to be determined for particular situations and checked by testing shall be generalized.

2. Force and energetic characteristics calculus

Speaking of bucket wheel excavators, the force characteristics mean the forces which act on the bucket and the wheel.

The forces which act on the bucket are: the cutting force (digging) F_x which acts according to the tangency of the trajectory of the bucket; the penetration force (pressure) F_y which acts according to the normal of the trajectory of the bucket; the lateral force F_z which acts according to the binormal of the trajectory of the bucket.

The forces which act on the wheel are: the resultant cutting force F_{xR}; the resultant penetration force F_{yR}; the resultant lateral force F_{zR}.

Energetic characteristics mean: the required excavation power P_{ex}; the power required for lifting the material P_r; the power required for operating the wheel P; the power required for rotating (swinging) the superior platform of the excavator together with the arrow and the operating wheel P_p.

The force and energetic parameters depend on the period of time and on the parameters of the dislodged piece. Average values are being used in practice.

The average cutting force F_{xm} will be determined with the following relation:

- in the main vertical plane ($\theta = 0$):

$$F_{xm} = k_{uz} K_e S_{tm} \text{ , N} \qquad (1)$$

- in a plan with the angle $\theta \neq 0$ in relation to the main vertical plane:

$$F_{xm}(\theta) = k_{uz} K_e S_t(\theta) \text{, N} \qquad (2)$$

where: K_e represents the specific resistance of the excavated material to the cutting force, i.e. N/cm^2; S_{tm} – is the average surface of the transversal section of the chip, i.e. cm^2; θ – is the positioning angle of the bucket in relation to the axis of the main cutting vertical plane, i.e. rad; k_{uz} - represents the coefficient regarding the wear of teeth and cutting wedge of the bucket (k_{uz} = 1 for new tooth, k_{uz}= 1.2…1.5 for average worn teeth, $k_{uz} \geq 2$ for very worn teeth, k_{uz} being determined experimentally for each case).

The average value of the force F_{xm} is constant for $\theta \leq \theta_L$ and decreases if $\theta \geq \theta_L$, becoming F_{xm}=0 for $\theta = 90^o$, where θ_L is the limited pivoting angle.

The resultant cutting (digging) force acting on the wheel, in absolute value, will be determined with the following relation:

$$F_{xR} = \sum_{i=1}^{n_{ca}} F_{xm} = n_{ca} F_{xm} = n_{ca} k_{uz} K_e S_{tm} \text{ , N} \qquad (3)$$

or:

$$F_{xR} = k_{uz} K_e \sum_{i=1}^{n_{ca}} S_{ti} \text{ , N} \qquad (4)$$

where n_{ca} represents the number of active buckets in a given period of time, which is determined with the following relation:

$$n_{ca} = n_c \frac{\alpha_0}{2\pi}, \qquad (5)$$

where n_c represents the number of buckets on the wheel; α_0 – the chipping angle, rad.

The chipping angle will be determined with the following relation:

$$\alpha_0 = \arccos\left(1 - \frac{H}{R}\right)\text{, rad} \qquad (6)$$

where: H represents the cutting height equal to the height of the mined slice, m; R – the cutting radius, m.

The penetration force F_{ym} will be determined as follows:

$$F_{ym} = k_y k_{uz} K_e S_{tm} \text{ , N} \qquad (7)$$

where k_y represents the ratio between the penetration force F_y and the digging force F_x, which is determined experimentally.

The resultant penetration force acting on the wheel, (in N), in absolute value, can be determined starting from the relations (3) and (7) as follows:

$$F_{yR} = k_y \sum_{i=1}^{n_{ca}} F_{xm} = k_y k_{uz} K_e S_{tm} n_{ca} = k_y k_{uz} K_e \sum_{i=1}^{n_{ca}} S_{ti} \qquad (8)$$

The average lateral force F_{zm} may be determined as follows:

$$F_{zm} = k_z \cdot k_{uz} \cdot K_e \cdot S_{tm} \text{, N} \qquad (9)$$

where k_z represents the ratio between the lateral force F_z and the digging force F_x, which can be determined experimentally or:

$$F_{zm} = F_{ym} \frac{h_{mi}}{h_{mi} + b} \text{, N} \qquad (10)$$

where:

$$h_{mi} = h_m \cdot \cos\theta \text{ , m} \qquad (11)$$

In the relations (10) and (11), h_m represents the average thickness of the chip, m, and b is the width of the chip, m.

The resultant lateral force F_{zR} will be:

$$F_{zR} = k_z \cdot F_{xR} = F_{yR} \frac{h_m}{h_m + b}, \text{ N} \tag{12}$$

The literature says that the two components of the power necessary to drive the rotor can be determined in the following manner:

The power necessary for excavating purposes shall be determined with the help of the following equation:

$$P_{ex} = 10^{-3} F_{xR}\, v_t, \text{kW} \tag{13}$$

or:

$$P_{ex} = \frac{1}{360} k_{uz} K_e Q_m, \text{kW} \tag{14}$$

where: v_t represents cutting speed, m/s; Qm - momentary excavating capacity, m^3/h;

Momentary excavating capacity can be expressed as:

$$Q_m = 3600\, V_a z, m^3/h \tag{15}$$

where: V_a represents volume of the chip cut by the bucket, m^3; z - number of unloading operations performed by the buckets, s^{-1}.

The volume of the chip cut by the bucket is:

$$V_a = H\, h_0\, b, m^3/h \tag{16}$$

where: H represents cutting height of the rotor, m; h_0 - maximum width of the chip, m; b - width of the chip removed by the bucket, m.

The power required for lifting the material is determined based on the established parameters and also presented in figure 1.

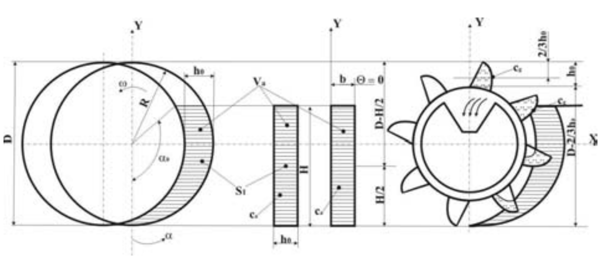


Fig.1 Determination of the power necessary to lift up the material

The weight of the chip material which already has the application point in the barycenter c_a, will be determined with the following relation:

$$G_a = \rho \cdot g \cdot V_a, \text{ kN} \tag{17}$$

where: ρ represents the density of the material inside the massive, t/m^3; g – gravitational acceleration, m/s^2.

The lifting height of the material H_r will be:

$$H_r = D - \frac{H}{2} - \frac{2}{3} h_c, \text{ m} \tag{18}$$

where h_c represents the active height of the bucket. The filled bucket has the barycenter c_g.

The lifting mechanical work is:

$$L_r = G_a \cdot H_r, \text{ kJ} \tag{19}$$

The lifting force resulting consequently:

$$P_r = \frac{L_r}{\Delta T} = L_r \cdot z, \text{ kW} \tag{20}$$

Thus resulting into the relation:

$$P_r = \frac{1}{3600 \cdot \eta_r} \left(D - \frac{H}{2} - \frac{2}{3} h_c \right) \rho_a\, g\, Q_T, \text{ kW} \tag{21}$$

where: η_r represents the efficiency of the loading-unloading process (according to the literature η_r = 0,6...0,7); $\rho_a = \rho / k_a$ - the bulk density of the material, t/m^3; k_a – bulk coefficient; D – wheel cutting diameter, m; Q_T – theoretical excavation capacity, m^3/h.

Considering the equations (13) or (14) and the equation (21), the power necessary for the motor driving shall take the following form:

$$P = \frac{P_{ex} + P_r}{\eta_t}, \text{kW} \tag{22}$$

where ηt is the transmission output between the rotor and the bucket wheel.
Consequently, we have (in kW):

$$P = \frac{Q_t}{3600 \eta_t} \left[\frac{10\, k_{uz} K_e}{k_a} + \frac{\rho_a g}{\eta_r} \left(D - \frac{H}{2} - \frac{2}{3} h_c \right) \right] \tag{23}$$

As the characteristics to cutting of rocks and of lignite (i.e. specific strength to cutting K_e, the wear coefficient k_{uz}, the density of the material ρ, the outputs η_t and η_r) are known because they have been determined during laboratory testing, then we can get the power and energy characteristics.

The required power for swinging the wheel may be determined as follows:

$$P_p = 10^{-3} \cdot F_{zR} \cdot v_p \, , \, kW \qquad (24)$$

where the swinging speed v_p depends on the swinging angle θ, if $\theta \leq \theta_L$, otherwise ($\theta > \theta_L$) decreases ans when $\theta = 90^o$ it becomes zero.

A very important aspect is to determine the momentary excavating capacity in relation to the installed power necessary for the rotor driving. The power necessary for the rotor driving shall not exceed at any time the rated power of the motor, i.e.:

$$P \leq P_N \, , kW \qquad (25)$$

The equation (25) above can be written in a simpler manner:

$$P = \frac{1}{3600\eta_t} Q_m C_e \leq P_N \, , \, kW \qquad (26)$$

where C_e represents extraction factor given by the equation:

$$C_e = 10 k_{uz} K_e + \frac{1}{\eta_r}\left(D - \frac{H}{2} - \frac{2}{3} h_c\right)\rho g \, , \, kW \qquad (27)$$

where: K_e is expressed in N/cm^2, D, H and h_c in m, ρ in t/m^3 and g in m/s^2. As a result, momentary excavating capacity, limited by the rated power of the motor shall be:

$$Q_m \leq \frac{3600 \, P \, \eta_t}{C_e} \, , \, m^3/h \qquad (28)$$

At the same time the momentary excavating capacity is also limited by the volume of bucket, presuming that it shall load up the whole amount of removed material, i.e.:

$$Q_m \leq 3600 \, V_c \, z \frac{k_u}{k_a} \, , \, m^3/h \qquad (29)$$

As it is necessary to correlate the cutting and loading operation, the following equation shall result:

- for the rotor equipped with cutting and loading buckets:

$$V_c \geq H \, S_t \, k_a \, , \, m^3 \qquad (30)$$

- for the rotor equipped with cutting and loading buckets and with cutting buckets:

$$V_c \geq 2 H S_t \, k_a \, , \, m^3 \qquad (31)$$

Considering the fact that the cutting and loading operation take place simultaneously, the period necessary to sweep up the distance between buckets along the outer edge, whit the cutting speed is the same with the period necessary to sweep up the width of the chip, with the swiveling speed.

Therefore, we have:

- for the rotor with one type of buckets:

$$v_p \leq \frac{V_c \, v_t \, n_c}{2\pi R H h_0 \, k_a} \, , m/s \qquad (32)$$

- for the rotor with two type of buckets:

$$v_p \leq \frac{V_c \, v_t \, n_c}{4\pi R H h_0 \, k_a} \, , m/s \qquad (33)$$

Halving the swiveling speed for the second situation is only ostensible because the effective power necessary for cutting and loading operations shall not depend linearly on the cutting capacity and on the power specific consumption during cutting and on the specific strength to cutting of the excavated rock.

In practice, the swiveling speed calculated with the equation (32) or (33) shall have to be achievable with an excavator, whit given technical data, which means that:

$$v_{p\,min} \leq v_p \leq v_{p\,max} \qquad (34)$$

where: v_{pmin} represents minimum swiveling speed; v_{pmax} – maximum swiveling speed. For example, for EsRc 1400 30/7 630 excavator, v_{pmin}= 0.1 m/s and v_{pmax}= 0.5 m/s.

3. Case study regarding excavators operating in the Oltenia basin

Be it the case of an excavator the maximum height of the excavated step H_{tmax} represents a technical characteristic given by the manufacturer. The height

H of a mined slice depends on the cutting diameter D of the wheel and on the stability of the mined rock.

The literature recommends that:

$$\frac{D}{2} \le H \le \frac{2}{3} D \qquad (35)$$

The minimum value is recommended when the rocks are unstable and there is the danger of the superior part of the extracted slice to slip after the passing of the wheel. Thus, the contact angle between the wheel and the massive is of $\alpha_o = 90^o$, i.e. H = R. The maximum value is recommended in the case of stable rocks, when, after the wheel has passed, the superior slice does not slip.

The number of extracted slices results from the following relation:

$$n_f = \frac{H_t}{H} \qquad (36)$$

where n_f has to be a round number.

If the relation H_t/H is not a round number for the values of H in order to respect the integrality (35), then a slice (the superior one recommended) will have to have the smallest thickness of them all. Although the idea to maintain the instant excavation capacity Q_m, the decrease of H may be compensated through the increase of the maximum thickness h_o of the chip, respectively the upper slice as close to the determined value with the relations (35) and (36), as h_o is limited by the active height h_c of the bucket, and the swinging speed v_p cannot go over the maximum value v_{pmax}.

Considering the entire technological process in the quarry and considering that the excavator is the main machinery during the process, it is recommended that it operates at a constant excavation debit in time. This may only be realized in given exploitation conditions if the excavator has been correctly chosen. The technological analysis of the excavation process during a swinging cycle has the purpose to determine the chipping parameters, of the excavation capacity, of the acting forces and of the required power during the process.

Table 1 represents the input data referring to the working conditions and the basic characteristics for EsRc 1400 and SRs1300 excavators.

Figure 2 represents an above view from of the excavated block and a vertical section through the wall towards the working direction of the excavator. With the considered excavators, the arrow has a constant length, that is why when extracting the slices on the length of the step, with the vertical chipping technology, the movement of the excavator to the center of swing is required from O1 to O4 with the pase DL.

Table 1 Technical and technological characteristics of bucket wheel excavators in lignite quarries in Oltenia

No.	Characteristic	Symb.	Unit	Value		Obs.
				EsRc 1400	SRs 1300	
1	Excavation step height	H_t	m	30	20	Resulted values from applied technology
2	Wall width	B	m	60	50	
3	Number of slices per step	n_f	pcs.	4	4	
4	Cutting height	H	m	7.5	5	
5	Swing angles left - right	θ_S θ_D	deg	Fig. 3, 4	Fig. 5, 6	
6	Wheel cutting diameter	D	m	11.5	8.4	Values resulted from excavator documentation
7	Bucket discharge number	z	s^{-1}	0.65/ 0.77	1.12/ 1.40	
8	Number of buckets: - cutting - loading - cutting	n_c	pcs.	18 20* 9 20 9 -	14 14 -	
9	Maximum chip thickness (advancing step)	h_o	m	0.6	0.5	Measured values
10	Excavation time for cutting on a slice	T	s	251	159	

* the data refer to the modernized type

Taking into consideration the above stated things, in order to determine the width of the right excavated block, respectively the left one, the determination relations have been reduced:

$$B_D^i = R_p^1 - (i-1)\Delta L + \Delta L_p^i \text{ , m} \qquad (37)$$

and

$$B_S^i = B - B_D^i \text{, m} \tag{38}$$

where: B_D^i and B_S^i represent the width of the right and left extracted block in slice i, m; i = 1, 2, ..., n_f – is the number of the extracted slice, the number being assigned downwards; R_p^1 - the swinging radius for slice 1, m; ΔL_p^i - the difference of the swinging length of the arrow of the wheel due to the changes of inclination when passing from a superior slice to an inferior one, m.

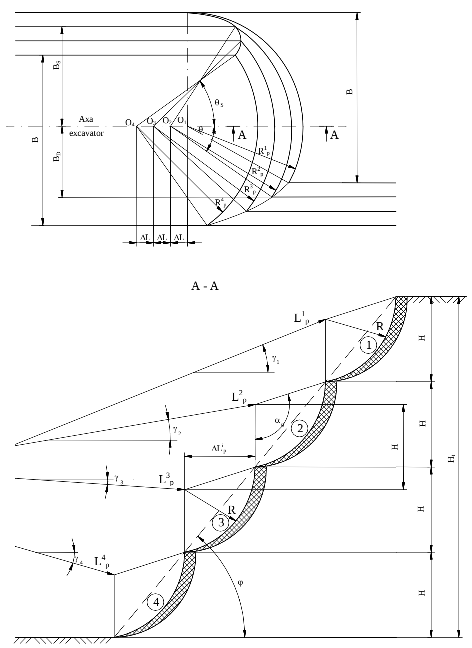


Fig.2 Vertical chipping excavation parameters

This may be determined using the following relation:

$$\Delta L_p^i = L_p(\cos\gamma_{i-1} - \cos\gamma_i)\text{,m} \tag{39}$$

In the relation (39) i has values between 2 and n_f. When choosing the initial data presented in table 1, the recommendations of the manufacturer have also been considered, as well as the existing conditions in the quarry, i.e. the width of the wall, the height of the excavation step, the number of slices on a step, the cutting height of the wheel and the maximum width of the chip. The period of excavation of a cutting on a slice was obtained by quarry timing.

The resulted geometrical parameters are presented in figure 3 for the EsRc 1400 type excavator in the 1st and the 2nd slice and figure 4 in the 3rd and the 4th slice respectively figure 5 for the SRs 1300 type excavator in the 1st and the 2nd slice and figure 6 in the 3rd and the 4th slice.

The 3rd slice has been chosen for both excavators in order to amplify, and the determined data are presented in detail in Table 2.

The technological analysis of the excavation process on a swinging cycle when being aware of the cutting parameters and also of the excavation capacity, based on the previously presented methodology, is useful considering at least two different points of view, i.e.:

- when designing a new quarry or new production capacity in a given quarry;
- when realizing a study regarding the operation of an excavator in given working conditions.

When designing a new quarry and the extraction technology, the analysis methodology offers useful data regarding the constructive-functional correlation between the characteristics of an excavator and the geometrical parameters of the excavated step.

The force and energetic characteristics have been determined and analysed for the exact case of lignite EsRc 1400 excavator and respectively those for the black-gray clay SRs 1300 type excavator.

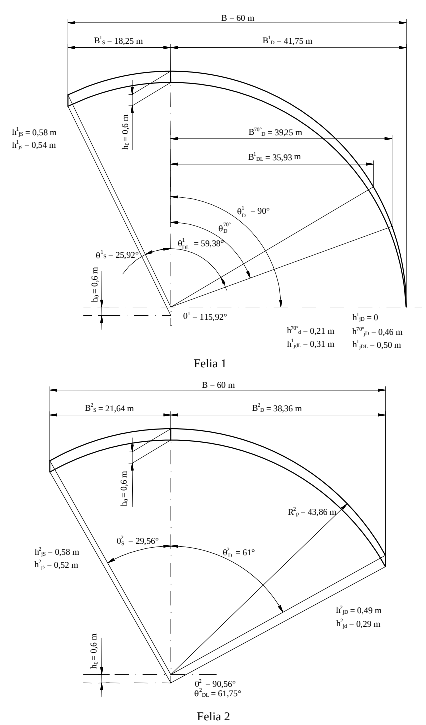


Fig.3 EsRc 1400 30/7·630 typeexcavator real extracting parameters in slices 1 and 2

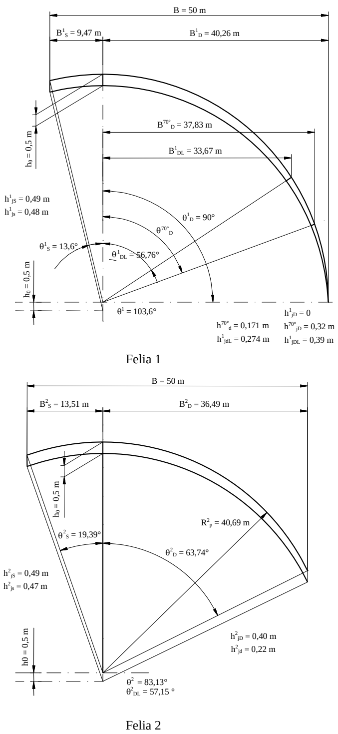


Fig.4 SRs 1300 26/3,5·500 type excavator real extracting parameters in slices 1 and 2

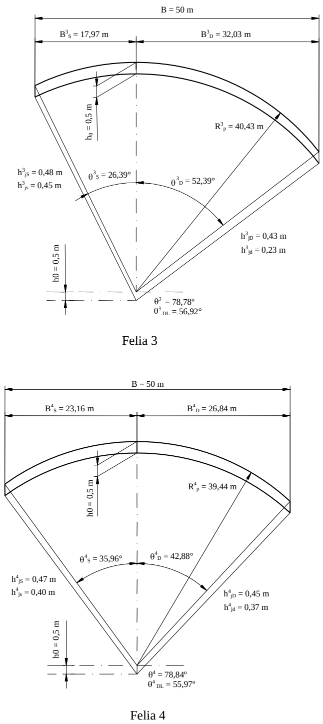


Fig.6 SRs 1300 26/3,5·500 type excavator real extracting parameters for slices 3 and 4

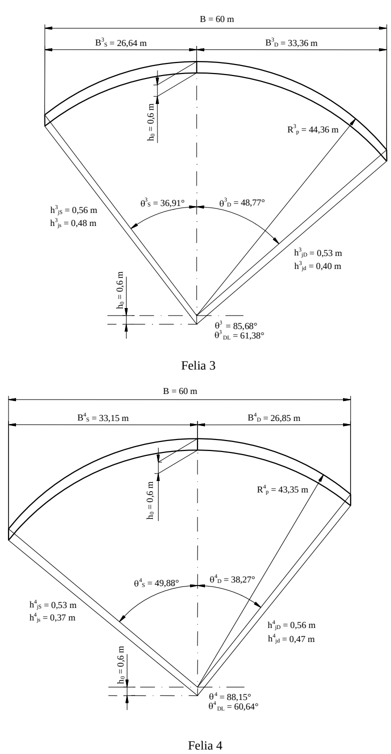


Fig.5 EsRc 1400 30/7·630 type excavator real extracting parameters in slices 3 and 4

Thus, the values representing the operational characteristics, respectively the dislodged material and the excavator, and which will be used directly in the determination of the force and energetic parameters are presented in table 3.

The calculated values of the forces on the bucket, respectively the resultant forces, the power requirement for excavation, swinging and lifting the material out of the buckets and the total power required for the operation of the wheel are given in table 4.

In all cases two values were obtained due to the fact that each excavator has two cutting speeds, respectively two rotation speed values which influence the other parameters.

It can be noticed that in the given conditions the power required for operating the wheel in both situations are greater than the power of the driving engines, from which results that in certain cases the excavator cannot work simultaneously at maximum excavating capacity and maximum power.

Considering the analysis, in relation (21) some of the values are constant, and other are variable in regard to the cutting capacity, respectively with the resistance specific for cutting the rocks.

Table 2 Cutting and excavating parameters

No	Parameter	Symb	Unit	Values		Obs.
				EsRc 1400	SRs 1300	
1	The swinging radius in the given slice	Rpi	m	44.36	40.48	Slice 3 is chosen
2	The positioning angle of the wheel	γi	deg	1.92	7.02	For slice 3
3	Maximum swing speed	vpmax	m/s	0.499	0.580	In slice 3
4	The right block length	BD	m	33.36	32.03	
5	The left block length	BS	m	26.64	17.97	The new created wall is on the right
6	The right swing angle	θD	deg	48.77	52.39	
7	The left swing angle	θS	deg	36.91	26.39	
8	Total swing angle	θ	deg	85.68	78.78	
9	Minimum thickness of the cutting in a right horizontal plane	hjd	m	0.40	0.23	
10	Minimum thickness of the cutting in a left horizontal plane	hjs	m	0.48	0.45	
11	Average thickness of the cutting in the main horizontal plane	hjm	m	0.54	0.455	
12	Wheel swing length	LH	m	66.34	55.59	
13	Average swing speed	vp	m/s	0.264	0.314	
14	Average width of the cutting *	b	m	0.4/ 0.34	0.28/ 0.22	
15	Average positioning angle of the bucket	θm	deg	25.84	24.49	
16	Swinging speed in the main vertical plane**	vp (θ = 0o)	m/s	0.223/ 0.264	0.265/ 0.314	
17	Maximum width of the cutting *	bmax	m	0.77/ 0.65	0.52/ 0.41	
18	The surface of the transversal section of the cutting in the main horizontal plane	Sh	m2	36	25	
19	The volume of a cutting in an excavation slice	Vf	m3	270	125	Felia 3

No	Parameter	Symb	Unit	Values		Obs.
				EsRc 1400	SRs 1300	
20.	Average excavation capacity	Qmed	m3/h	3872	2830	
21.	Cutting angle	αo	deg	107.70	1010	
22.	Average thickness of the cutting in the main vertical plane	hm	m	0.42	0.34	
23.	Tooth angle positioning *	αp	deg	5.79/ 4.89	8.48/ 6.79	

* - it will result in two different values, considering the two different possible
** - set value / constant value

Table 3 Values for the determination of force and energetic parameters

No.	Name	Symb	Unit	Values		Obs.
				Lignite	Grey Clay	
1.	Cutting resistance	K_e	N/cm^2	60	72	
2.	Tooth wear of	k_{uz}	-	1.2	1.2	
3.	Maximum cutting thickness	h_o	m	0.4	0.4	
4.	Average cutting thickness	h_m	m	0.251	0.243	Slice 3
5.	Plane width	b	m	0.4/0.34	0.28/0.22	
6.	Average surface of the transversal section of the chip	S_{tm}	m^2	0.1/0.085	0.068/0.053	
7.	Average number of active buckets	n_{ca}	pcs	5.38	3.93	
8.	Penetration forces coefficient	k_y	-	-0.3	0.05	
9.	Lateral forces coefficient	k_z	-	0.06	0.2	
10.	Bulk coefficient	k_a	-	1.35	1.25	
11.	Average swing speed	v_{pm}	m/s	0.26	0.31	
12.	Material density	ρ	t/m^3	1.3	2.0	
13.	Loading-unloading efficiency	η_r	-	0.7	0.7	
14.	Active height of the bucket	h_c	m	0.84	0.72	
15.	Theoretical digging capacity	Q_T	m^3/h	3280/3860	2820/3520	
16.	Wheel transmission efficiency	η_t	-	0.85	0.85	

Table 4 Excavator force and energetic parameters

No	Specification	Symb	Unit	Values	
				EsRc 1400	SRs 1300
1.	Average cutting force on a bucket	F_{xm}	N	72 000	58 752
				61 200	45 792
2.	Resultant cutting force	F_{xR}	N	387 360	230 895
				329 256	179 963
3.	Power required for excavation	P_{ex}	kW	1007	487
				1014	475

No	Specification	Symb	Unit	Values	
				EsRc 1400	SRs 1300
4.	Average penetration force	F_{ym}	N	-21 600	2 938
				-18 360	2 290
5.	Resultant penetration force	F_{yR}	N	-116 208	11 546
				-98 777	8 998
6.	Average lateral force	F_{zm}	N	4 320	11 750
				3 672	9 158
7.	Resultant lateral force	F_{zR}	N	23 242	46 178
				19 755	35 992
8.	Power required for swinging	P_p	kW	6.04	14.32
				5.14	11.16
9.	Power required for material lifting	P_r	kW	104	118.8
				88.4	95.2
10.	Power required for operating the wheel	P	kW	1307	712
				1296	671

Thus, for given conditions and for a given excavator, the following function may be written:

$$P = \left(k_1 K_e + k_2\right) Q_T \text{, kW} \qquad (40)$$

where:

$$k_1 = \frac{k_{uz}}{3.6 \cdot 10^2 k_a \eta_t}, \qquad (41)$$

$$k_2 = \frac{\rho g \left(D - \frac{H}{2} - \frac{2}{3} h_c\right)}{3.6 \cdot 10^3 k_a \eta_t}, \text{ kWh/m}^3 \qquad (42)$$

Considering the physical interpretation of the relation (40), then the product k_1K_e represents the specific energy consumption for cutting, and k_2 the specific energy consumption for lifting-hauling the excavated rock.

Explaining the cutting capacity Q_T in the relation (40), the following result is given:

$$Q_T = \frac{P}{k_1 K_e + k_2}, \text{ m}^3\text{/h} \qquad (43)$$

In the relation (40) for the given excavator in given conditions P, k_1 and k_2 are considered to be constant, and K_e is an independent variable.

Taking into account that the installed power for the operation of the wheel is limited, in a normal operating regime $P \le P_N$, and in extremis $P \le \lambda\ P_N$, where P_N represents the nominal power of the engine, and λ represents the overload coefficient of the motor.

For the E_sR_c 1400·30/7·630 type excavator, considering the relation (40), in a nominal operating regime, applying the relation (43) it results:

$$Q_T = \frac{630}{2.9 \cdot 10^{-3} K_e + 0.0222}, \text{ m}^3\text{/h} \qquad (44)$$

By representing graphically the function (44) we obtain the variation curve of the excavating capacity as a function of the specific cutting resistance given in figure 7. In an analogue way, graphically representing the function (40) for $Q = Q_N = 3860$ m^3/h (the cutting speed being 3.08 m/s) we obtain a straight line represented also in figure 7, having the following expression:

$$P = 11.21 K_e + 85.67 \text{, kW} \qquad (45)$$

For the SRs 1300·26/3,5·500 type excavator it results:

$$Q_T = \frac{500}{3.44 \cdot 10^{-3} K_e + 0.0278}, \text{ m}^3\text{/h} \qquad (46)$$

And for $Q_T = Q_N = 3520$ m^3/h (the cutting speed being 2,64 m/s) a straight line with the following equation is obtained:

$$P = 12.11 K_e + 97.86 \text{, kW} \qquad (47)$$

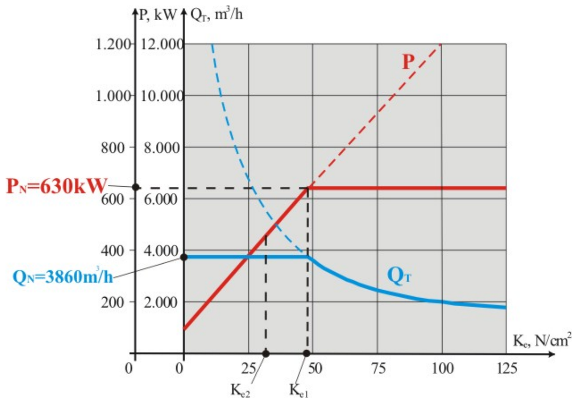


Fig.7 Dependence of the power and excavating capacity on the specific cutting resistance for the EsRc 1400·30/7·630 type excavator

Both the curve $Q_T = f(K_e)$, as well as the straight line $P = f(K_e)$ are represented in figure 8.

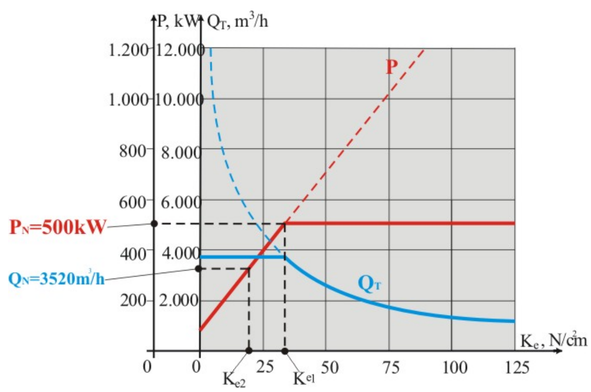


Fig.8 Dependence of the power and excavating capacity on the specific cutting resistance for the SRs 1300·26/3,5·500 type excavator

As it may be seen from the two figures 7 and 8, both the power P and the theoretical excavating capacity Q_T have a linear variation, respectively a hyperbolical one, theoretically continuous, but if the specific cutting resistance goes over a certain value equal to K_{e1} then the excavating rate Q_T decreases with the increase of K_e, the power remaining constant around the nominal value P_N.

On the other hand, if the specific cutting resistance K_e decreases, the excavating rate remains at its nominal value Q_N, but the required power for the operating motor of the wheel decreases linearly. Because the engines are asynchronous ones, on the basis of their characteristic curves resulting that functioning lower than 70 % of P_N is a disadvantage because the efficiency and power factor decreases the use of excavator for specific cutting resistances below the value K_{e2} is not recommended.

Starting from the relation of the power, the two limit boundaries of the specific cutting resistance, K_{e1} and K_{e2}, will result:

$$K_{e1} = \frac{1}{k_1}\left(\frac{P_N}{Q_N} - k_2\right),\ \text{N/cm}^2 \tag{48}$$

and

$$K_{e2} = \frac{1}{k_1}\left(\frac{\delta\, P_N}{Q_N} - k_2\right),\ \text{N/cm}^2 \tag{49}$$

where δ represents the allowed underload of the engine.

The superior limit K_{e1} is a restrictive one, because over this limit the excavator is operating under its nominal excavation rate in an extreme operating regime.

The lower limit K_{e2} is recommended, taking it in respect allowing the work of the excavator at nominal capacity but in a disadvantageous regime of the engine.

Using the relations (48) and (49) for the E_sR_c 1400·30/7·630 type excavator, the limits $K_{e1} \cong 48.62$ N/cm²; $K_{e2} \cong 31{,}74$ N/cm² will result, as seen in figure 7, and for the SRs 1300·26/3,5·500 type excavator, the two limits are $K_{e1} = 33.21$ N/cm² and $K_{e2} = 20.12$ N/cm², as seen in figure 8.

The instant excavating rate can be limited by the operating power, by the volume of the buckets and by the capacity of conveying line, if the later is lower than the other two ones. Certainly, the excavation rate can be also limited by the power of the swinging mechanism of the superior platform. The required swinging power will be determined by the relation (24) to which the required power for bringing to the excavator to the horizontal, if necessary, is added.

Concretely, for the two studied cases, it results that both lignite as well as clay have specific cutting resistance greater than the limit K_{e1}, from which results that in the given conditions both excavators will operate at a value of power near to the nominal one, with excavating capacity decreased as it can be seen in the figures 7 and 8.

It also results that the two studied cases may constitute the basis for implementing an automated command and control equipment for the operation of the cutting-hauling system, both for the excavator as well as for the entire technological line.

4. Software to analyze the excavating parameters with the view to determining the working mode

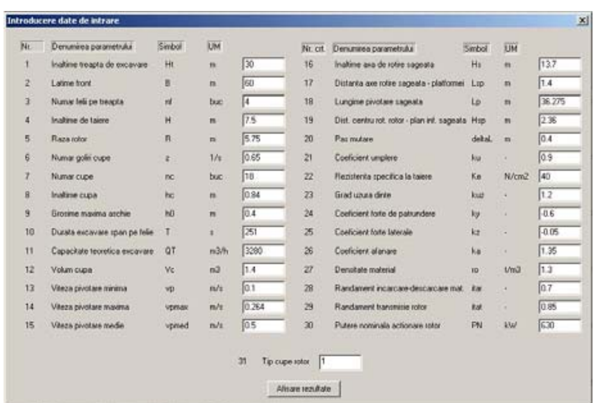
By using the aforementioned equations, which are valid for any type of rotor excavator in operation in Oltenia coalfield, we have developed software that calculates the excavating parameters and the power and energy characteristics of the cutting – loading system. We introduce the required input data, run the software and finally we can get the numerical values of the monitored parameters.

For this application the inputs are being characterized by 31 dimensions that are in relation with the mining method, with the nature of the mined material and with the geometrical characteristics and kinematics of the cutting – loading systems (wheel – bucket carrier and swiveling systems) of the rotor excavators.

This application is in C++ and uses MFC (Microsoft Foundation Classes) and the development environment is Visual C++6.0. This application has been tested on the operating system Windows XP. This software comprises three classes: Image, Inputs and Outputs.

Beside the 31 dimensions said above, the inputs also include the code lines that allow the calculation of the excavating parameters.

Figure 9 shows a screen capture with all the fields for the data input.


Introducere date de intrare

Nr.	Denumirea parametrului	Simbol	UM	
1	Inaltime treapta de excavare	Ht	m	30
2	Latime front	B	m	60
3	Numar felii pe treapta	nf	buc	4
4	Inaltime de taiere	H	m	7.5
5	Raza rotor	R	m	5.75
6	Numar goliri cupe	z	1/s	0.65
7	Numar cupe	nc	buc	18
8	Inaltime cupa	hc	m	0.84
9	Grosime maxima aschie	h0	m	0.4
10	Durata excavare span pe felie	T	s	251
11	Capacitate teoretica excavare	QT	m3/h	3280
12	Volum cupa	Vc	m3	1.4
13	Viteza pivotare minima	vp	m/s	0.1
14	Viteza pivotare maxima	vpmax	m/s	0.264
15	Viteza pivotare medie	vpmed	m/s	0.5

Nr. crt.	Denumirea parametrului	Simbol	UM	
16	Inaltime axa de rotire sageata	Hs	m	13.7
17	Distanta axe rotire sageata - platformei	Lsp	m	1.4
18	Lungime pivotare sageata	Lp	m	36.275
19	Dist. centru rot. rotor - plan inf. sageata	Hsp	m	2.36
20	Pas mutare	deltaL	m	0.4
21	Coeficient umplere	ku	-	0.9
22	Rezistenta specifica la taiere	Ke	N/cm2	40
23	Grad uzura dinte	kuz	-	1.2
24	Coeficient forte de patrundere	ky	-	-0.6
25	Coeficient forte laterale	kz	-	-0.05
26	Coeficient afanare	ka	-	1.35
27	Densitate material	ro	t/m3	1.3
28	Randament incarcare-descarcare mat.	etar	-	0.7
29	Randament transmisie rotor	etat	-	0.85
30	Putere nominala actionare rotor	PN	kW	630

31 Tip cupe rotor 1

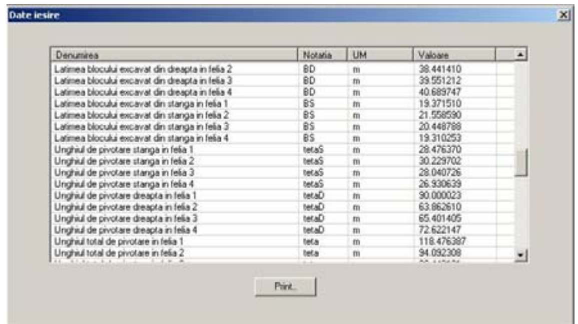
Afisare rezultate

Fig. 9. Table with the input data necessary to runt he application

The outputs are under the form of tables and include the calculated parameters together with their names, the measuring units as well their numerical values.

The final output data incorporates the messages that confirm or refute the verification conditions required by the constructive and operating characteristics of the excavator. The structure of the table with the output data shall structure automatically depending on the input data.

Figure 10 shows the table with the calculated values.


Date iesire

Denumirea	Notatia	UM	Valoare
Latimea blocului excavat din dreapta in felia 2	BD	m	38.441410
Latimea blocului excavat din dreapta in felia 3	BD	m	39.551212
Latimea blocului excavat din dreapta in felia 4	BD	m	40.689747
Latimea blocului excavat din stanga in felia 1	BS	m	19.371510
Latimea blocului excavat din stanga in felia 2	BS	m	21.558590
Latimea blocului excavat din stanga in felia 3	BS	m	20.448788
Latimea blocului excavat din stanga in felia 4	BS	m	19.310253
Unghiul de pivotare stanga in felia 1	tetaS	m	28.476370
Unghiul de pivotare stanga in felia 2	tetaS	m	30.229702
Unghiul de pivotare stanga in felia 3	tetaS	m	28.040726
Unghiul de pivotare stanga in felia 4	tetaS	m	26.930639
Unghiul de pivotare dreapta in felia 1	tetaD	m	90.000023
Unghiul de pivotare dreapta in felia 2	tetaD	m	63.862610
Unghiul de pivotare dreapta in felia 3	tetaD	m	65.401405
Unghiul de pivotare dreapta in felia 4	tetaD	m	72.622147
Unghiul total de pivotare in felia 1	teta	m	118.476387
Unghiul total de pivotare in felia 2	teta	m	94.092308

Print...

Fig.10 Screen capture with a part from the table with the output data

For using this software, the following aspects shall be considered:

- all cases in the table with the input data shall be filled in (zero value is not allowed); all the inputs shall be positive, except the positions 24 and 25 where these values can be negative;
- position 31 makes reference to the type of cutting buckets in operation on the excavator under analysis;number 1 shall be used for the excavators with cutting – loading buckets;
- number 2 shall be used for the excavators with cutting buckets and with cutting – loading buckets.

5 Conclusions

The assessment of working parameters of a bucket wheel excavator in order to insure a proper operating regime is a very important and difficult task.

Among the basic operating parameters of the rotor excavators the most important are the main drive absorbed power, the excavation capacity and the specific power consumption. The main drive power covers the power necessary to cut the rock and the power necessary to lift up the removed material by the buckets for their further haulage and discharge. Among these two components, the basic one is the cutting power that represents between 60 and 90% of the power necessary to drive on the rotor. The knowledge of the power for given working conditions is important for an increased efficiency of the mechanized cutting, both from the power consumption point of view and from the point of view of the cutting capacity, i.e. the final output.

A graphical analytical method has been worked out, based on derived power and cutting capacity as functions of the specific cutting resistance on the which are plotted on the same graph. Using this, it is possible to establish the proper working regime of the excavator, avoiding the overload of the drive and maintaining the maximal cutting capacity in each case.

A computer software has been provided to calculate on the basis of this reasoning the proper working parameters for a given rock characteristic in the case of the most widely used excavtors in Oltenia coalfield. Two case studies for lignite and sandy marl for a representative excavator type in a given open pit mine.

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