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RESEARCH REGARDING THE IMPROVEMENT OF THE WORKING PARTS OF THE BUCKET WHEEL EXCAVATORS

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Abstract: The paper deals with the research performed at the department of Machines, Installation and Transport of the University of Petroşani, regarding the improvement of the working parts (bucket and teeth) of the rotor excavators widely used in Romanian open pit lignite mines, for the excavation of the lignite and the overburden rocks.

The research pathway is presented, with the obtained results, starting from reduced scale cutting tests performed on samples using a self-devised testing rig, the theoretical fitting of obtained results in the frame of a theory, devising and developing prototype teeth and buckets on this basis, until the validation of results using in situ field measurements on operating excavators, using a self-devised measuring/tele-transmitting/storing computerized system.

Keywords: excavators, lignite, lignite, overburden rocks

1. INTRODUCTION

Bucket wheel excavator represents the main equipment used in open pit lignite mines, both in excavating lignite and overburden rock. In Romania, about 30 million tons of lignite per year is produced using this technology, in Oltenia Coalfield open pits. An amount of 300 million tons of overburden rock is produced in same time. The most 30 widely excavators are E_SR_C- 1400 — 630 and SRs 1300 26/3.5 500 types.

The main mining operators, SNLO (National Lignite Society Oltenia) and the 3 Energetic Complexes are facing various technical problems, among which, energy consumption and teeth wear represents a huge share in operating costs.

Actual energy consumption of 0.5-0.6 kWh/mc representing an amount of 150-160 GWh leading to 16,000,000 € of energy consumption and 50000 pcs worn teeth of metal (alloy steel) representing annual loses, considering the production loses during teeth replacement and supplementary manpower consumption. It is obvious that by

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increasing teeth lifetime and reducing specific energy consumption by an appropriate design, we can reduce costs and in a certain manner increase productivity. In the mentioned processes, the teeth geometry, material, placement layout, bucket shape, are parameters highly responsible in the improvement aimed. In this respect, using previous experience, we have started with experimental researches of cutting with different shape of teeth on samples collected among major coal seams and coalfields in the region.

One of the major problems of the increasing the energy effectiveness of the mechanical coal and rock cutting in open pit mines is the knowledge of the mechanical cutting governing laws, which represents interdependences between different parameters, in order to derive the optimization decisions. The involved parameters, in their large majority, expose a heavily random character, and the correlations between them are difficult to be derived by heuristic reasoning. In this respect, the establishment of the characteristics of the mechanical rock cutting, both qualitative and quantitative, for each case, must be performed on the basis of experimentally obtained data, fitted into theory and validated via field measurements. On this background, new teeth, bucket and eventually wheel can be devised.

In the actual paper, the pathway and results of the researches performed in the past few years on this issue at the Mineral Resources Equipment and Technology Research Center (MRETRC) of the Faculty of Mechanical and Electrical Engineering from the University of Petroșani are presented.

2. LABORATORY TESTS

At the Rock Cutting Laboratory of the Mining Equipment and Technology Research Center, fundamental research was performed for the determination of the cutting characteristics of coal and rocks at different mining fields of Romania.

The experimental research was performed on a self-designed and devised testing rig, presented in fig.l a, and the data were recorded using a DAQ device, presented in fig. l,b.

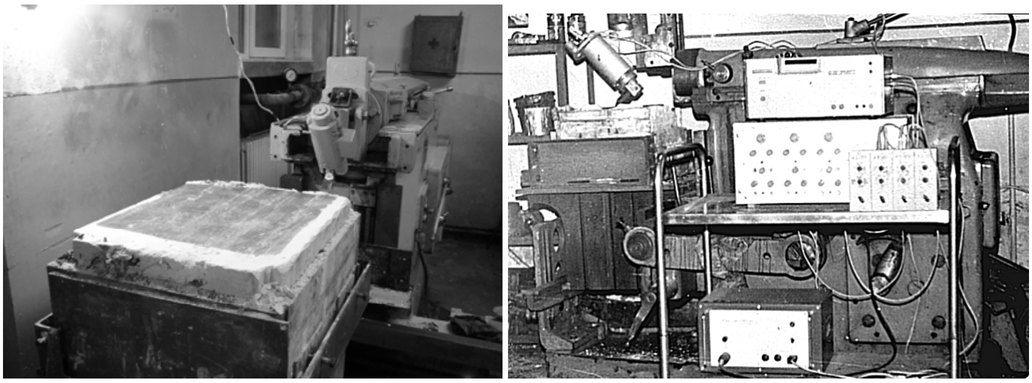

Fig.1. Experimental setup : a) testing rig; b) measuring device

Using this experimental arrangement, the diagrams of the variation in time of the cutting forces, F_x, penetration forces, F_y, and lateral forces, F_z, acting on the assay teeth were recorded. In whole, an amount of 1600 cuts were performed on 12 lignite samples and 20 overburden rock samples (1 m^3 each) were performed, and the corresponding data were recorded in digital form. A sample of recorded diagram for the force F_x , displayed using MathCad is shown in fig. 2. On the diagram, the maximal value F_{xraax}, the average valueF_{xm}, the peak average F_{xtnv} are marked.

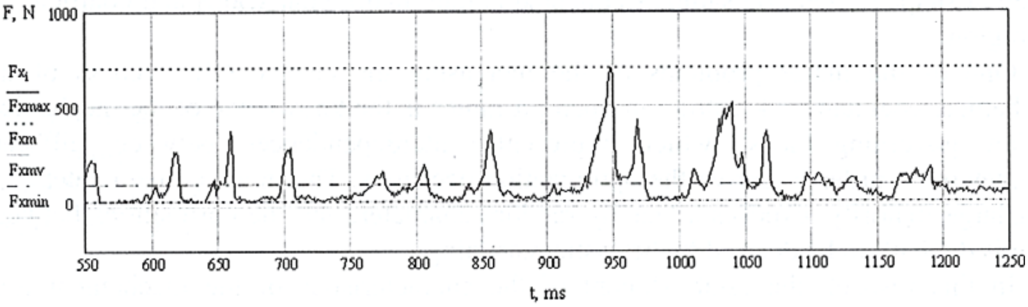

Fig.2. Sample recorded diagram

In the same time the volume of rock removed at each experiment was measured, in order to establish the chip slope angle ψ and the specific energy consumption. The removed chip volume was determined by filling the trace of cut with plaster and measuring the volume in a measuring glass.

Using the average values, the dependences between cutting force F_x and the depth of cut h_0 were plotted, as in fig. 3, as point values and regression lines. With these values, for each location of collected samples and each type of assay tooth, the following characteristics can be determined:

- Specific cutting resistance of the lignite A relative to the depth of cut h_0:

$$A = \frac{F_{xm}}{h_0}, N/cm \tag{1}$$

- Specific cutting insistence of the lignite A_t relative to the width of the cutting edge, b:

$$A_1 = \frac{F_{xm}}{b}, N/cm \tag{2}$$

- Specific cutting resistance of the lignite K_e, relative to the cross section area of the slice, S_0:

$$K_e = \frac{F_{xm}}{S_0}, N/cm^2 \tag{3}$$

- Chip slope angle ψ, the angle between the tool axis and the chip removal line is determined by:

$$\psi = arctg\left(\frac{S_0}{h_0^2} - \frac{b}{h_0}\right) \tag{4}$$

- Specific energy consumption, E_s , depending on chip volume, V_0 and length of cut, 1, is given by:

$$E_s = \frac{E}{V_0} = \frac{F_{xm} \cdot 1}{S_0 \cdot 1} = \frac{F_{xm}}{S_0} = \frac{A \cdot h_0}{S_0}, kWh/m^3 \tag{5}$$

3. TRANSLATING EXPERIMENTAL RESULTS FOR REAL WORKING CONDITIONS USING ANALOGY

In order to determine the value of the forces in real conditions, on the basis of dependences previously mentioned we can apply the laws of similitude to transcalculate the experimentally obtained data on scale reduced teeth towards the real scale machine.

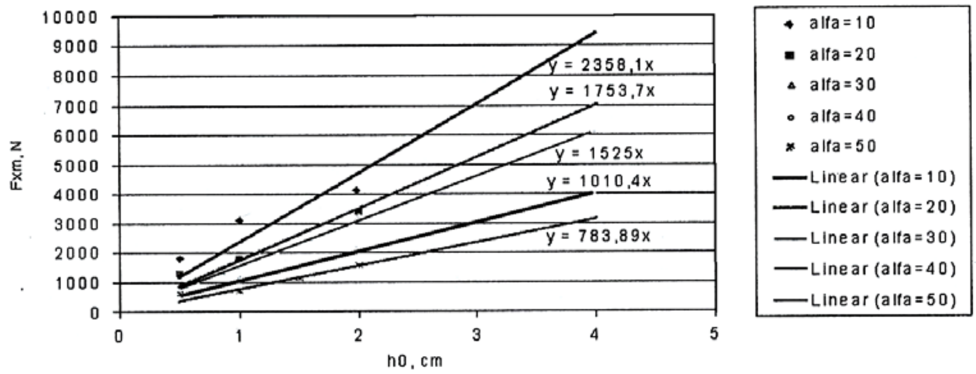

Fig.3. Dependence of average drag force F_{xm} on the depth of cut h_0 for different values of rake angle of teeth, a

We note F'_{xm} the average real force for a tooth with a width b', relative to the value of the force F_{xm} established by laboratory test for an assay tooth with width b = 4 cm and taking into account the relations defining the three variants of the specific resistance we can calculate the real forces as follows:

$$F'_{xm} = \frac{Ah'_0}{b} b', N \tag{6}$$

where h'_o and S'_o represents the depth respectively the cross section area of the real slice in the studied case.

In order to exemplify the switching from laboratory testing results to the most probable values for a given real case, a tooth whit the attack angle α =50° was chosen, the assay tooth having a width b = 4 cm, and the real teeth having a width b’ = 12 cm.

Choosing as real example the classic bucket wheel excavator, E_SR_C- 1400 30/7 630, with teeth parameters as shown previously and the depth of the slice dislocated by a bucket between 0,3...0,5 m we have the resulting real thickness of the chip cut by one tooth to have a medium value of h'_o = 15 cm.

Based on the most probable tearing angle of the chips form the massif ψ = 65°, it results an area of the transversal chip section of S'_o =662,5 cm^2.

Based on these data and applying the equations (8).. .(19), the most probable values for the forces acting on a tooth of the bucket wheel excavator in the excavating process results, according to table 1.

Table 1. Translated values from experimental to real scale

Tooth type	Force F_X,N k_w	In laboratory conditions			In real working conditions		
		F_{xm}	F_{xmv}	F_{xmax}	F'_{xm}	F'_{xmv}	F'_{xmax}
New	1	2276	2200	17070	35354	33940	265156
Normally worn	1,2	2731	2640	20484	42425	40728	318187
	1,5	3414	3300	25605	53031	50910	397734
Heavily worn	2,0	4552	4400	34140	70708	67880	530312
	2,5	5690	5500	42675	88385	84850	662890

4. IN SITU EXPERIMENTAL RESEARCH RELATED TO THE ENERGETIC CHARACTERISTICS

4.1. Power measurements

In order to verify the obtained results, using the presented methodology, field researches were performed in the conditions of Lupoaia open pita t the excavator E-04 of type SRs 1300 in the level II of overburden excavation (black grey clay).

The measurements were made in the conditions existing at that moment, in the overburden strata two narrow lignite layers being presents.

An amount of 17 measurements were performed, from which 11 in the upper slice and 6 the lower slice between the two layers of lignite. The active power P, the reactive power Q, the intensity I of the current absorbed by the engine and the power factor cos φ, were measured , knowing the width of the face B, the height of the layer (slice), the pivoting radius R_p, the maximal depth of chip h_0, the duration of a complete excavation where measured and the pivoting sense (left or right) was considered.

The working scheme of the excavator operation during the measurements in the upper slice is presented in the figure 4, and during the measurements in the lower slice in the figure 5. In the table 3 the data measured in the two situations are summarized. In order to compare the calculated values on basis of the results measured and results of laboratory tests the record no. 25 was chosen.

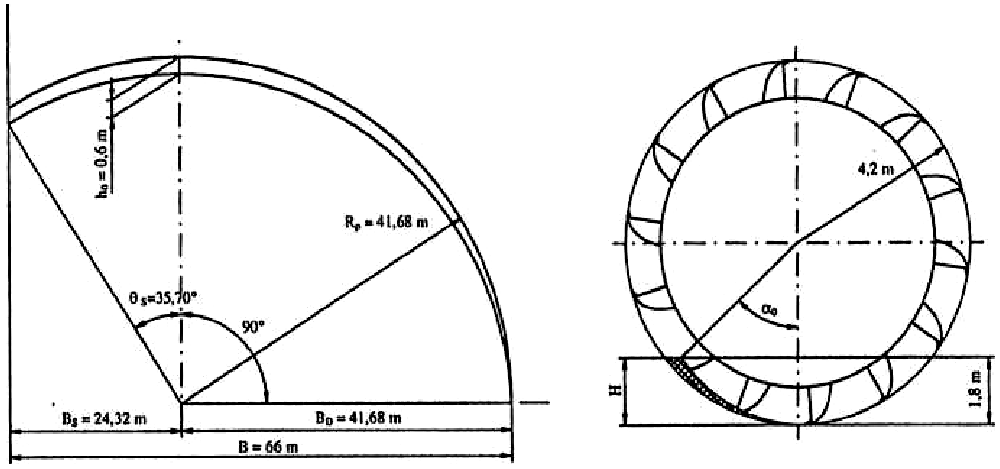

Fig. 4. Working scheme of the excavator E-04 during measurements (uper slice)

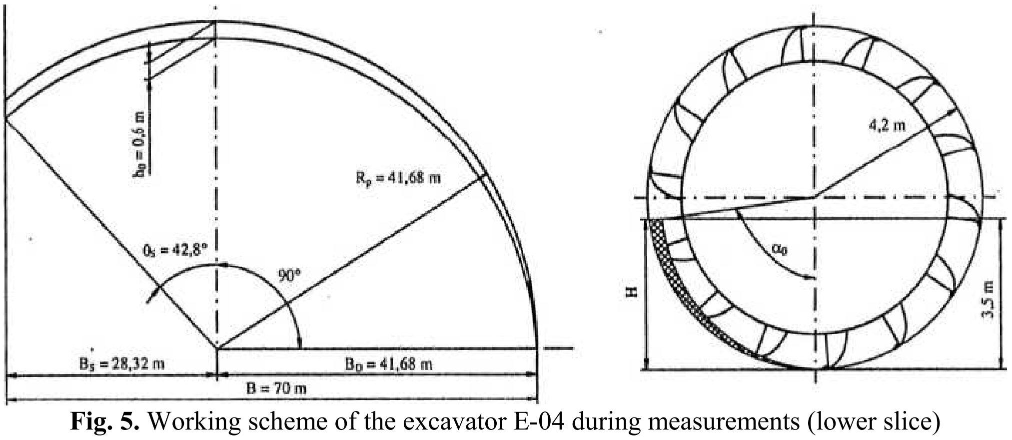

Fig. 5. Working scheme of the excavator E-04 during measurements (lower slice)

The measured diagram is shown in figure 6. The concluding data are presented in the table 4.

From the analysis of data it results that the difference between the calculated power and the measured power the difference is small (about 16 kW), which means 5%. Taking into account the random character of the characteristics exposed by the cutting of rocks, this difference is acceptable.

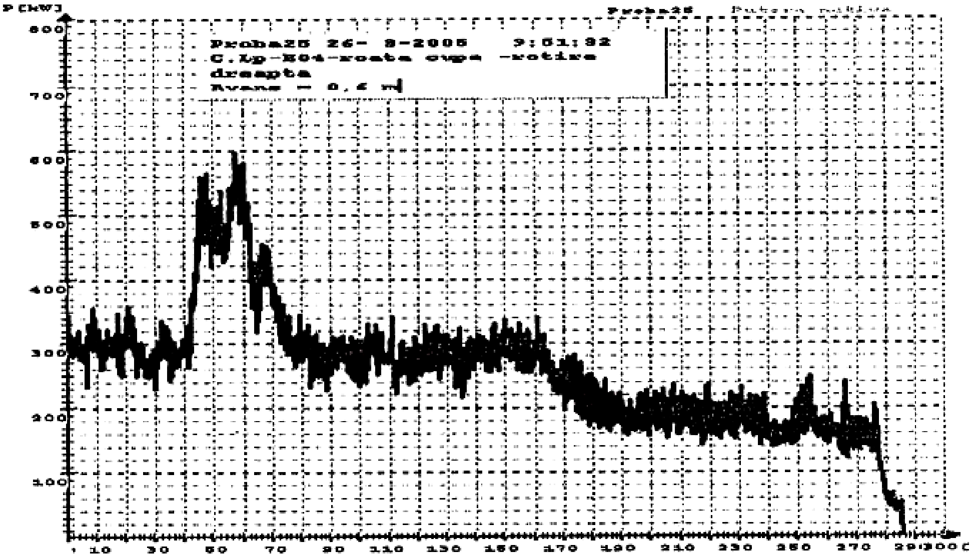

Fig.6. Recorded diagram of power (Rec.26)

Table 2. Directly measured parameters

No.	Parameter	Symbol	Unit of measure	Values for assay no. 25
1.	Maximal chip depth	h_0	m	0,6
2.	Duration of excavating one slice	T	s	428
3.	Sense of rotation	-	-	to right
4.	Width of excavated block	B	m	70
5.	Pivoting radius	R_P	m	41,68
6.	Height of slice	H	m	3,5
7.	Status of teeth	-	-	new
8.	Grade of wear	k_{uz}	-	1

Table 3. Data necessary for the correlation between power and excavating rate

No	H m	ho m	b m	z S^{-1}	Q_{med} m^3/h	P_{imed} kW	No of record	V_p m/s
1.	1,8	0,6	0,482	1,12	2099	340	16; 17	0,54
2.	1,8	0,7	0,473	1,12	2403	327	19; 22	0,53
3.	1,8	0,8	0,455	1,12	2642	345^*	23; 24	0,51
4.	3,5	0,6	0,205	1,12	1736	347	25; 26	0,23
5.	3,5	0,7	0,198	1,12	1956	300	28; 29	0,222
6.	3,5	0,8	0,196	1,12	2213	325	30; 31	0,22

Table 4. Parameters calculated on basis of measurements

No	Parameter	Symbol	Unit of Measure	Values
1.	Average chip depth	h_m	m	0,257
2.	Slice width	b	m	0,164
3.	Pivoting speed	V_p	m/s	0,23
4.	Cross section area of chip	S_{trn}	m^2	0,042
5.	Average number of active buckets	η_{ca}	buc.	3,11
6.	Pivoting angle to left	θ_s	grade	42,8°
7.	Pivoting angle to right	θ_D	grade	90°
8.	Overall pivoting angle	θ	grade	132,8°
9.	Working angle of bucket	α_0	grade	80°
10.	Length of slice in horizontal plane	L_H	m	96,6
11.	Length of slice in vertical plane	L_v	m	5,86
12.	Average cutting force on a bucket	F_{xm}	N	30.346
13.	Resultant cutting force	F_{xR}	N	94.378
14.	Power required for excavation	P_{ex}	kW	200
15.	Power requirement for lifting	P_r	kW	67
16.	Power required for actuating the wheel	P	kW	314
17.	Instantaneous excavating rate	Q_m	m^3/h	1389
18.	Excavating rate	Q	m^3/h	1736
19.	Average recorded power	P_i	kW	298
20.	Difference between calculated and measured power	ΔP	kW	16
21.	Relative difference	ε_p	%	5,09

4.2. On teeth force measurements

Recently, direct field measurements were performed using force transducer teeth mounted on bucket with wireless data transmission. The transducer teeth (using resistive strain gages) are shown in fig. 7 and the recorded signal obtained from the 4 teeth on 3 axes.

In this respect, a measurement, wireless transmission and data acquisition device vas used, as a result of a research grant contracted with the National Authority for Research.

On the basis of the results of these measurements , we were able after data processing to highlight some new aspects of the excavation process, as the unbalanced distribution of forces among teeth and the variation of mean values on contact angle as in Fig. 8.

The data measured is according to those calculated, so the energy requirement for cutting is correctly determined .

As a result of the researches, a new teeth geometry (Fig.9) and bucket layout (fig. 10) was designed, which results will be assessed during the next stage of field measurements. We estimate a total energy reduction of 30%.

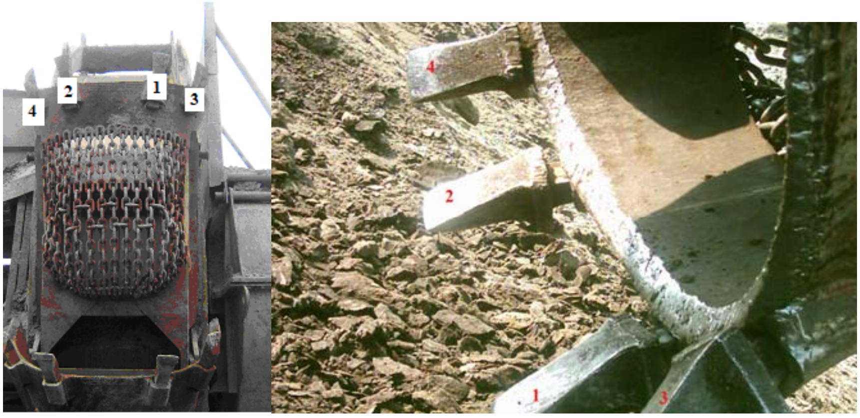

Fig.7. Teeth transducers mounted on the bucket

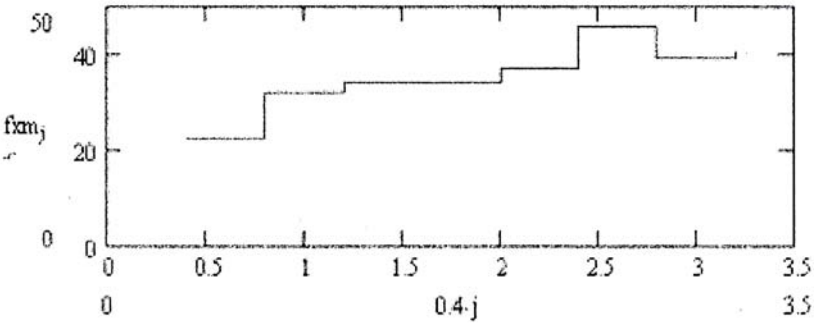

Fig.8. Varation of average force, cutting in lignite, tooth 4

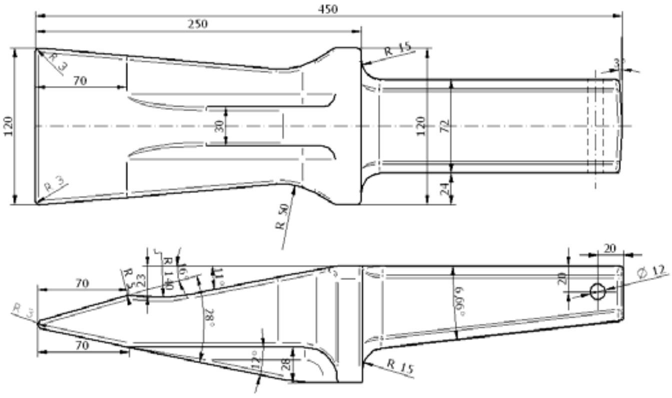

Fig.9. New tooth design

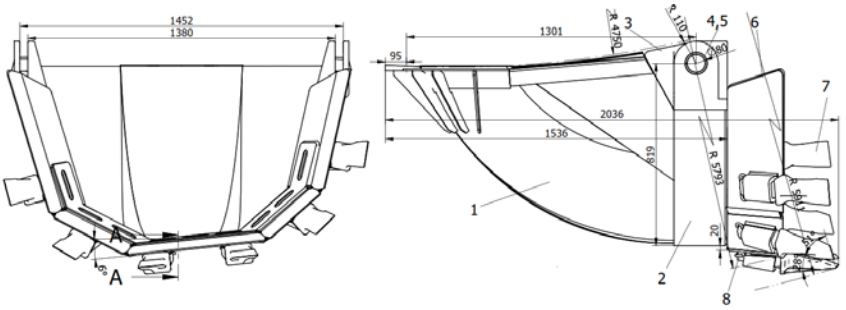

Fig. 10. New bucket layout design

5. CONCLUSION

On the basis of the methodology of analytical determination of force and energetic characteristics, starting from the results of experimental results in laboratory and taking into account the technical characteristics of the excavators, the dependence of the power as a function of rock cutting specific resistance has been studied.

The dependence diagrams of the power on the cutting specific resistance were obtained for both excavators in given working conditions, resulting the operating limits of the excavator's parameters.

In order to validate the results obtained using the delivered methodology, field tests were performed with the same excavator. The data resulted from measurements is near to the calculated ones in an interval of 5% which means the methodology and laboratory results are corrects.

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