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Professional paper

APPLICATION OF EXPERIMENT PLANNING AND ANALYSIS TO BUCKET-WHEEL EXCAVATORS IN OPEN-PIT MINES

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Abstract

In the conditions either of the production practice ore on research, there are numerous occasions when the theoretical knowledge is insufficient, the only way with which we can have a satisfactory acknowledge of different technological phenomena or processes remains always the statistical planning of experiments. For a general experimental study of such a process, we must take into consideration many indicators with the aim of overcoming all the difficulties in the examination and optimization of such a process according to the indicators. However, the problem solution that provides satisfactory reports of indicators can be achieved by implementing a regressive analysis of the experiment through comprehensive factor 2k plans. Such plans can be applied with adequate success in correlation with the technical and technological parameters in the practice of superficial usage bucket wheel excavators. This paper presents the correlation of technical and technological parameters during the work of excavator SchRs 650 for working conditions in overburden on an open pit mine in Kosova.

Key words: application of experiment, planning and analysis, bucket-wheel excavators, open-pit mines.

1 Introduction

Rational exploitation of the equipment with continual activity depends on a great number of factors such as: constructive, technological, natural, and climatic. The depending scale of these factors is defined in base of their correlation scale. The correlation of the technological and technical parameters in surface exploitation represents a very complicated process because it depends from **case to case** and from the digging formation. The clay formations of Kosovo differ from the formations of the other deposits in the physical-mechanical characteristics if it considers the works' technology. That is why the main scope of this study is the establishment of the technical and technological scale of the correlation factors.

$$(Qh,N,e,kL) = f\ (S,h,vk) \quad (1)$$

According to orthogonal plans of the second order **2k** through the mathematical experimentation theory with factors such as: slice thickness, "S", cutting height "h" Fig .1 and the moving velocity of the working wing "vk". Quite often, after the capital repairs or different modifications done with chain-bucket excavator excavators, is necessary to complete the capacity test or the technical promptness test for this equipment, to have a clear panorama of the repair argumentation.

The study presented in this paper, presents a new method in this field aiming the study of the reports between the technical and technological parameters, enabling the enlargement of such parameter's specter. In this case, it can be taken more information comparing with the other parameters carried out in different cases.

2 The experiment plan

The correlation of the technical and technological parameters, based on the data related to orthogonal coordinates of the second order 2k, k aims the increase the exploitation scale of the capacity as well as decrease the specific consumption of electric energy. In these cases are presented the mathematical models which express the dependence between these technical (Qh, N, e, kL), and technological parameters (S, h, vk). For this reason, the relation between the above-mentioned parameters can be expressed through the formula

$$R=C\,S^{p_1}h^{p_2}v_k^{p_3} \qquad (2)$$

which represents the interlacement of the technological and technical parameters, enabling the enlargement of such parameter’s spectre. In this case we can obtain more information comparing with the other parameters performed in different periods of time.

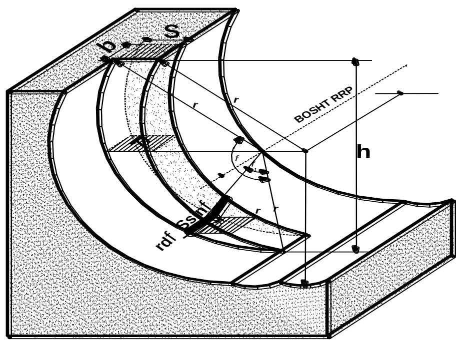

Figure1. Technological parameters

In this case, formula (1) can be transformed in a derivative form: R{Qh, N, e, kL} (2)The definition of the incognito parameters C,p1,p2, and p3 and the formula (2) can be performed through the statistical elaboration of the results and in these cases we have in all :

N=2k+no where:

k-the number of the parameters, k=3, ***no***- the number of the measurements in the center of the experiment plan no=4.After the calculations, the result is: N=23+4=12[measurements]. For the simpler presentation of the values of the parameters in the measurement process of the hour capacity of the chain-bucket excavator “Qh” and other parameters such as the power in the active axe “N”, specific consumption of the electric energy "e” and the cutting force exercised "kL”, it must present the planning matrix of the experiment plan. Before presenting the matrix it must be performed the variables (S,h,vk) codification through the values (-1,0,+1), presenting

1 bottom limit value
0 average limit value
+1 upper limit value

The codification or transformation equation of the real values is performed through the formula:

$$x_i = 1 + 2\frac{\ln f_i - \ln f_{i\max}}{\ln f_{i\max} - \ln f_{i\min}} \qquad (3)$$

where:

f_i- presents the limit values of the variation interval of the parameters which means that if: $\mathbf{f_i=f_{imax}}$ then the coded value will be x_i= +1, meanwhile if $\mathbf{f_i=f_{imin}}$ the coded value will be x_i=-1. The planning matrix of the study is presented for real and coded values of the technological parameters as well as some technical parameters such as Q_h, N, e and k_L, with the proper values presented in table 1. To avoid any eventual mistake, the choice of parameters is based on random selection.

In the case of the capacity of the chain-bucket excavator measurement before the beginning of the study of the parameters relations, we must define the initial values of the experiment plan. At the same time these values present the average value of the verification procedure parameters of the excavator (SchRs650) capacity and in this case, are completed 59 measurements the measurements are completed conform to the technology projected by the constructer who guarantees a capacity of 2000[m3/h]. The measurement values of the above-mentioned parameters are carried out considering the average values of the parameters

-Slice thickness **S=0.45[m]**

-Cutting height **h=4.5[m]**

-Wing speed **v_k=19[m]**

Thus, from these parameters' values can be asked the question if we can preliminarily determine the research steps or if they can be predetermined. In each case, they must fulfil the condition:

$$f_{mes} = \sqrt{f_{\max} f_{\min}} \quad (4)$$

Because in this case is not given the variation step, the research step for each parameter can be elected according to the will, anyway in this case it must be considered that the parameters that are supposed to affect the process, must be undertaken complete the smallest step meanwhile for the factors that slightly effect the process must be undertaken the biggest step. According to the above principle the steps of the parameters are:

-Slice thickness h_1=0.15

-Cutting height h_2=1

-wing speed h_3=1

In these conditions the parameters limits will be:
1: slice thickness

1. the bottom limit, S=0.3[m]
2. the upper. limit, S=0.6[m]

2: Cutting height

1. upper limit=5.5[m]
2. bottom limit h=3.5[m]

3: Wing's movement speed- limit

1. bottom limit v_k=18[m/min]
2. upper limit v_k=20[m/min]

TABLE1. PLAN MATRIX OF THE 2^K EXPERIMENT

No	Real variables			Coded variables				y_i
	S	h	v_k	X_0	X_1	X_2	X_3	

1	0.3	3.5	18	+1	-1	-1	-1	y_1
2	0.45	4.5	19	+1	0	0	0	y_2
3	0.6	3.5	18	+1	+1	-1	-1	y_3
4	0.3	5.5	18	+1	-1	+1	-1	y_4
5	0.45	4.5	19	+1	0	0	0	y_5
6	0.6	5.5	18	+1	+1	+1	-1	y_6
7	0.45	4.5	19	+1	0	0	0	y_7
8	0.3	3.5	20	+1	-1	-1	+1	y_8
9	0.6	3.5	20	+1	+1	-1	+1	y_9
10	0.45	4.5	19	+1	0	0	0	y_{10}
11	0.3	5.5	20	+1	-1	+1	+1	y_{11}
12	0.6	5.5	20	+1	+1	+1	+1	y_{12}

3 Measurements of the technical parameters

For the accomplishment of the measurements faze of the hour capacity "Qh" active power "N" with which is performed the digging process, specific electric energy consumption "e" and the cutting specific force "kL" exercised of the working wheel in the digging rocks must be also defined. The hour capacity "Qh" for these types of excavators has been made through photometric measurements and weighing equipment of the TT227N, UTEZ Celje, made in Slovenia. Figure below:

Figure 2. Weighing equipment type TT227N,

The active power working wheel RRRR is defined by multiple equipment's METREL type (INSTALTEST 61557 MI 2087)

Figure 3. Multiple equipment's METREL used for active power measurements

Specific electric energy consumption expresses the ration between active power of the working wheel and the hour capacity of the excavator as below:

$$e = \frac{N}{Q_{ef}} \quad [kWh/m^3] \qquad (6)$$

Specific cutting force „k_L” in this case has been calculated through the formula:

$$k_L = \frac{335.2\eta N - 0.913 Q_{ef} D\gamma g}{\sqrt{Q_{ef} D n_{zb} \varphi}} \quad [daN/cm] \quad (7)$$

TABLE2. THE TECHNICAL PARAMETERS ACHIEVE BY THE MEASUREMENTS.

No	Technical parameters „y_i”			
	Q_h [m^3/h]	N [kW]	e [kWh/m^3]	k_L [daN/cm]
1	1160	467	0.40	44
2	2200	663	0.30	92
3	2300	679	0.30	103
4	1795	592	0.33	69
5	2200	663	0.30	92
6	3450	853	0.25	130
7	2200	663	0.30	92
8	1300	496	0.38	56
9	2500	712	0.28	112
10	2200	663	0.30	92
11	2000	629	0.31	78
12	3900	900	0.23	145

4 The analyse of the measurement results

The mathematical analyse of the technological parameters during the optimisation of the equipment capacity, must be done aiming the perform of the mathematical models, which express the nature relation of technical and technological working parameters of the bucket and chains excavators. Such mathematical models represent the possible values of technological parameters which have been reached during the verification capacity of bucket and chains excavators, SchRs 650 type. In this case the proper surface to have a linear shape as below:

$$y = b_o + \sum_{i=1}^{n=3} b_i x_i \qquad (8)$$

Based on the fact that in this case is asked to approach the regress surface, in which are included different factors as: slice thickness” S”, cutting height **“h”**, working wing movement speed of the excavator “$\mathbf{v_k}$”, expressing the regress surface parameters with: x_1=**S**, x_2=**h** and x_3= $\mathbf{v_k}$, its form will be:

$$y = b_o + b_1x_1 + b_2x_2 + b_3x_3$$

which must be transformed in a logarithmic function as below:

$$\ln R = \ln C + p_1 \ln S + p_2 \ln h + p_3 \ln v_k \qquad (9)$$

Variables, which take part in this logarithmic function, are:

$y = \ln R \quad x_1 = \ln S$

$$x_2=\ln h \quad x_3=\ln v_k$$

Meanwhile, the coefficients next to the variables are substituted with the transformation equation as below:

$$b_0=\ln C \quad p_1=b_1$$

$$p_2=b_2 \quad p_3=b_3$$

So, as a result the expression of the regress surface will be transformed as below:

$$R=C\, S^{p_1} h^{p_2} v_k^{p_3}$$

According to the formula (3), regarding variables **xi** has formed the matrix of the experimentation plan 2k+no, in the case when k=3, the matrix of the experimentation plan takes this form meanwhile, the order of the factors can be done randomly. In the base of the orthogonal characteristic, which must complete the matrices, it is enabled that the regress equation coefficient "**bi**", can be defined through the formula below:

$$b_i=\frac{1}{p}\sum_{n=1}^{p} x_{iu} y_u \qquad (10)$$

After the definition of the regress coefficients (mathematical model) and based on the pre-determinate conditions is done the transformation of the equation in its initial form, through the formula below:

$$p_i=\frac{2b_i}{\ln\left(\frac{f_{i\max}}{f_{i\min}}\right)}$$

$$p_o=\left| \left|\sum_{n=1}^{3} b_i\right|_{i=0,1,2,3} - \left|\sum_{n=1}^{3} p_i \ln\left(f_{i\max}\right)\right|_{i=1,2,3} \right| \qquad (11)$$

The definition of these parameters can go beyond equation (2) profiting from the correlations between technical and technological parameters. Following this, according to the F criteria the evaluation of the statistical significance, comparing the distribution in the zero point, has been done.

$$\mathbf{F}=\frac{s_i^2}{S_E^2} > F_t^* \qquad (12)$$

Model parameters distribution is calculated according to the following ration:

$$S_i^2=\frac{s_i^2}{f_i} \qquad (13)$$

Meanwhile, the sum of the second exponent is defined following the formula:

$$Sb_i=b_i\sum_{n=1}^{p} x_{iu} y_u = N_i b_i^2 \qquad (14)$$

where i=0,1,2,3.There are treated two cases for the parameters as follow:

i=0 N=12
i=1,2,3 N=8

For this case are secured the freedom degrees "$\mathbf{f^i}$", meanwhile the distribution around zero point is calculated as below:

$$S_E^2 = \frac{S_E}{f_E}$$

The sum of the second exponent is defined following the formula:

$$S_E^2 = \sum_{n=1}^{4}(y_{ou} - y_o^2) = \sum_{u=1}^{4} y_{ou}^2 - \frac{1}{n_0}(\sum_{u=1}^{4} y_{ou})^2 \qquad (15)$$

In this case, the freedom degrees are calculated following the formula: $\mathbf{f_E = n_o - 1}$. When the certain level is "α" and $F_l > F_t^*$,the parameters "$\mathbf{b_i}$" are significant, in the contrary cases these parameters must be excluded from the mathematical model. Each mathematical model, that describes a working process of the systems or the represents an event must define the confidence interval according to the criteria "**F**", for the certain level "**α**".

$$F_l < F_t^* , \qquad (16)$$

As the central point is at the same plan in which the experiment is repeated $\mathbf{n_0}$-times, then the F calculated value –Fi , necessary for the definition of the certain interval of the mathematical model is expressed by the following form:

$$F_{l_{LF}} = \frac{S_M^2}{S_E^2} \qquad (17)$$

The difference between the experiment values "$\mathbf{y_i}$" and the calculated values " $\hat{y}_i$ " is expressed as follow:

$$S_M^2 = \frac{S_{LE}}{f_{LE}} = \frac{S_R - S_E}{f_R - f_E} \qquad (18)$$

Or if it is expressed according to the disintegrated equation will have the following dispersion:

$$S_M^2 = \frac{1}{f_R - f_E}\{ \sum_{u=1}^{12}(y_u - \hat{y})^2 - (\sum_{u=1}^{4} y_{ou}^2 - \frac{1}{n_o}(\sum_{u=1}^{4} y_{ou})^2) \}$$

Meanwhile the measurements results dispersion with a medium level is calculated following this formula:

$$S_M^2 = \frac{1}{f_E}\{\sum_{u=1}^{4} y_{ou}^2 - \frac{1}{n_0}(\sum_{n=1}^{12} y_{0u}^2)^2\} \qquad (19)$$

For this reason the **"F"** criteria value, are preliminary selected from the proper tables with the solution with the level of the certain level.

$$f_{LE} = f_R - f_E \qquad (20)$$

and $f_E = n_0 - 1$

The regressive and dispersive analyse and the correlation of the parameters is done by analysing the technological parameters which have an important indication during the definition of the technical parameters reached during the capacity determination phase. In this stage can be found the correlation between these parameters and using formula (2), can be given the correlation equations of different parameters such as:

Hour capacity „Q_h",
Active power of the working wheel , "N",
Electric energy specific consumption "e",
Specific cutting force.
The graphic „3D" of the technological and technical parameters correlation for each case is performed using MATLAB software .

-Hour Capacity:

$\mathbf{Q} = 117\ S^{0.287}\ h^{0.274}\ v_k^{0.934}$

-Active Power :

$$N=186.5S^{0.334}\ h^{0.36}\ v_k^{0.343}$$

- Specific electric energy consumption

$$\mathbf{e}=1.59\ S^{0.04}\ h^{0.08}\ v_k^{-0.590}$$

-Cutting specific force

$$\mathbf{k}_L=13.64S^{0.383}h^{0.411}v_k^{0.407}$$

Below are presented the graphics interpretation of the profited correlation for the cutting height h= h=4.[m]

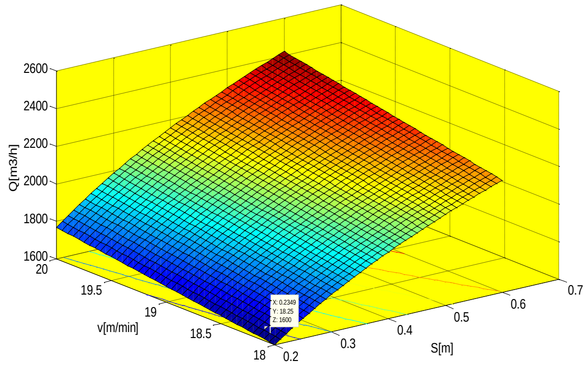

Figure 4. Hour capacity correlation “Qh” from slice thickness “S” and the working wing movement speed,”vk”

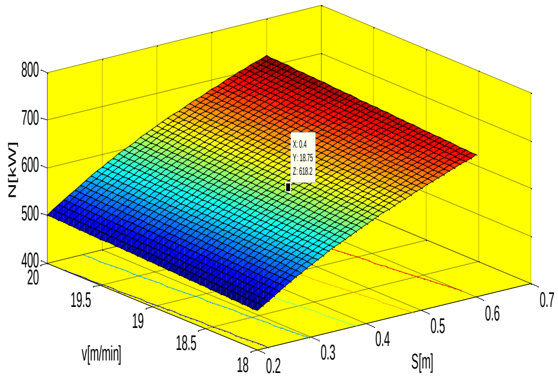

Figure 5. The correlation of the active power working wheel “N” from the slice thickness “S” and moving speed of the working wing”v”

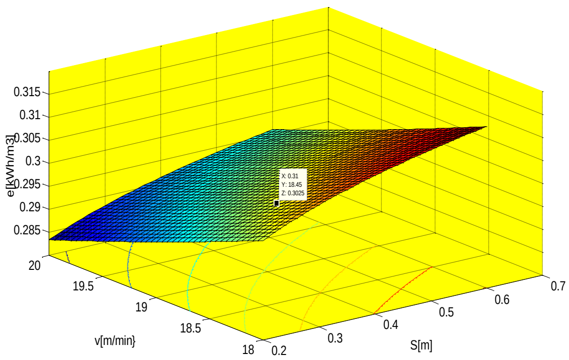

Figure 6. The correlation between the specific electric energy consumption “e” , slice thickness “S” and the working wing movement speed “v_k” .

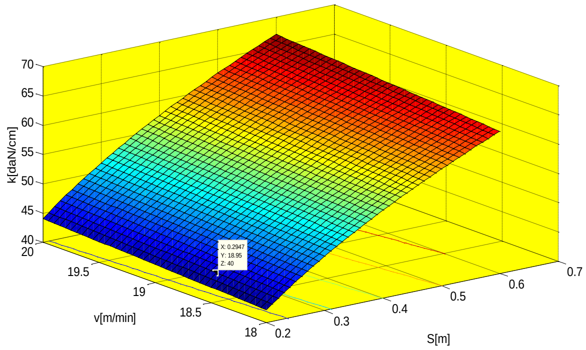

Figure 7. The correlation between the cutting force”k_L” slice thickness “S” and working wing movement speed”v_k”

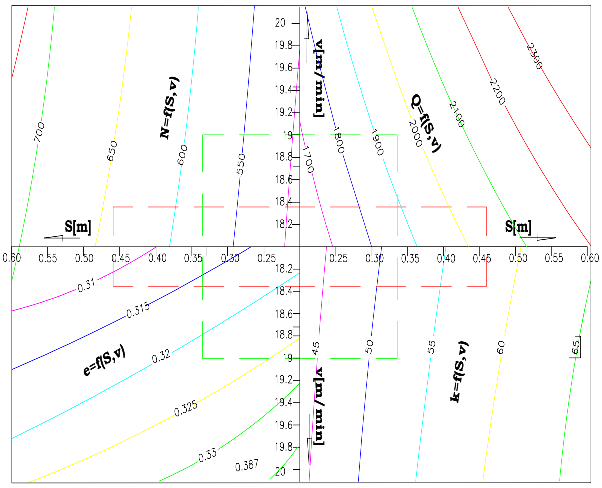

Figure 8. The nomogram of the technical and technological parameters correlation for the cutting height h=4[m]

Conclusions

In the base of profited diagrams and as a result of the result elaboration through the regressive and dispersive analysis according to the orthogonal plans "2k’’ of experiment with technological parameters of the working process of the rotor excavators, in the case of their correlation with the technical parameters and come to this result: the profited values of the technical parameters according to the correlation equation are almost the same with the values profited from the verification process of these excavators capacities if we own the technological parameters from the interval the presented variation in this study. The correlation of the technical and technological parameters based on such scientific studies presents a safe basement for the prediction of the hour capacity and other indicators for these excavators' working conditions (SchRs650) in MS. KOSOVA, based on the compatibility of the mathematical model solution.

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