SOME ISSUES OF THE TECHNOLOGICAL DESIGN OF BUCKET-WHEEL EXCAVATORS

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Abstract: For up-to-date bucket-wheel excavators with constant jib length, the most widespread winning technology is block mining in upper excavation. Designing the technology, one has to choose the chip and block parameters in such a way as to minimise the winning outside the limit angle. The optimal operating conditions have to be sought and chosen in the complicated and multi-parameter relation system between the cutting characteristics of the rock to be cut, the technical parameters of the bucket-wheel machine and the characteristics of the applied technology, in such a way as to achieve the highest possible winning efficiency with the lowest possible cost input.

Keywords: bucket-wheel excavators, technological design

1. TYPICAL TECHNOLOGY USED IN DOMESTIC SURFACE MINING

For up-to-date bucket-wheel excavators with constant jib length, the most widespread winning technology is block mining in upper excavation. The winning method for the block and the slices is shown in Figure 1. The greatest block height can be achieved with vertical chips. Measurements prove that the specific energy consumption and the dynamic effect on the bucket-wheel are the lowest here. The efficiency of the excavator is the highest in cases b and d. Therefore, it is reasonable to work with the vertical multi-row chips (case b). In Hungary, this is the typical technology in the mines of Visonta and Bükkábrány. Designing the technology, we are also examining this technology. For this technology, the main winning operation is side swinging. The block to be cut is divided into several slices and the individual slices are cut advancing downwards.

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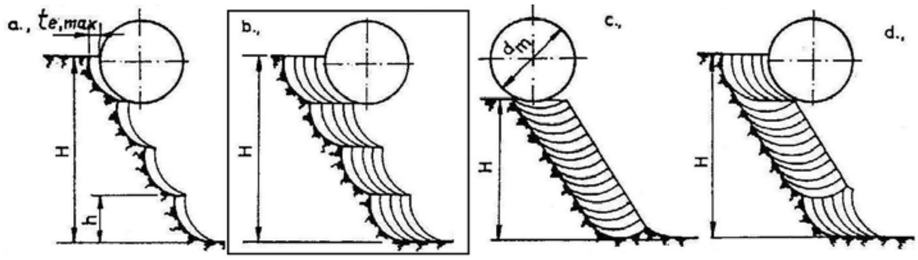

Fig. 1. The winning method for the block and the slices

2. ISSUES OF CHOOSING THE OPTIMAL TECHNOLOGICAL PARAMETERS

For the operation of a given bucket-wheel excavator in a certain rock environment, one must establish optimal technological conditions so that the excavator can produce the maximum winning efficiency continuously. The purpose of technology design is to determine the range of **momentary** winning efficiency in which the machine is able to operate with the given rock characteristics and technical conditions because there exist technological parameter ranges (so one can specify them) whose observation will result in the highest **average** winning efficiency. The excavator is likely to operate optimally in this range, taking into account the economic points of view. The technical conditions for this must be ensured continuously. The optimal operating conditions have to be sought and chosen in the complicated and multi-parameter relation system between the cutting characteristics of the rock to be cut, the technical parameters of the bucket-wheel machine and the characteristics of the applied technology, in such a way as to achieve the highest possible winning efficiency with the lowest possible cost input.

So one can determine the optimal technological parameters by simultaneously examining the following limits:

a) bucket volume limit,
b) power limit for the bucket-wheel drive,
c) swinging speed limit,
d) bucket geometry limit,
e) power limit for the turn mechanism drive.

If necessitated by the conditions, the loadability limits of the machine – strength and stability limits – must be examined, too.

A technology can be considered optimal if, for the excavator operating in the given rock environment, one can achieve the maximum winning efficiency for each swinging cycle without exceeding the limits.

ad a) Bucket volume limit:

The momentary winning efficiency cannot be greater than the effective winning efficiency determined from the nominal volume of the bucket, tacking into account the actual scarifying factor of the material cut and the permissible bucket efficiency:

$$Q_{jöv}^{töm} \leq Q_{eff}^{töm} \tag{1}$$

ad b) Power limit for the bucket-wheel drive:

The average power of the bucket-wheel drive in continuous operation cannot be greater than the nominal power of the driving motor:

$$\bar{P}_M \leq P_{M,mot} \tag{2}$$

ad c) Bucket geometry limit:

The maximum depth of cut cannot be greater than a geometric size determined by the bucket construction and the cutting tooth arrangement, as depths of cut greater than this result in unfavourable winning conditions. The maximum depth of cut can be chosen according to the chip pictures.

ad d) Swinging speed limit:

In continuous operation, the swinging speed in the full cross-section of the block being cut must not permanently reach the maximum swinging speed typical of the given jib position:

$$v_L(\alpha) < v_{L\max} \tag{3}$$

Ad e) Power limit for the turn mechanism drive:

In continuous operation, the average power of the turn mechanism drive cannot be greater than the nominal power of the turn motor. (We do not deal with this condition in the present paper).

3. STEPS OF DETERMINING THE OPTIMAL TECHNOLOGICAL PARAMETERS

From the conditions under item 2, the optimal range of the technological parameters can be determined through the following steps:

Step 1: Considering the volume limit:

$$Q_{jöv}^{töm} \leq Q_{elm}^{laza} \cdot \frac{k_{tölt}}{k_{laz}} = V_M \cdot n_ü \cdot \frac{k_{tölt}}{k_{laz}} \tag{4}$$

Step 2: Determining the momentary winning efficiency, starting from the driving power limit:

$$Q_{jöv}^{töm} \leq \frac{\eta_h \cdot P_{M,mot}}{T_{J,E}}, \text{ solid m}^3\text{/h} \tag{5}$$

where

$$T_{J,E} = \left(k_K \cdot f_v + \frac{1}{\eta_{em}} h_{em} \cdot \rho_t \cdot g \right) \tag{6}$$

As can be seen, $T_{J,E}$ takes into account the workability of the rock, the condition of the tool, the sizes of the block and the slice as well as the density of the material.

From the winning efficiencies obtained in steps 1 and 2, the smaller one is relevant. For loose rocks with small specific cutting strength, the limit is usually given by the first condition, while for more solid rocks with greater specific cutting strength, by the second condition.

Step 3: Determining the maximum depth of cut (advance) according to the chip picture drawn for the momentary winning efficiencies.

This is how the depth of cut is chosen according to the geometric limit.

Step 4: Determining the optimal range of the depth of cut

It can be usually chosen if the sizes of the block to be cut and the geometric sizes of the jib and the bucket-wheel are known. To choose the slice thickness, the characteristics of the material to be cut must be taken into account. For the range $Q_{jöv}^{töm}$ determined in step 2, the swinging speeds can be obtained using the realistic values of t_e. From this, the contact swinging angle (α_H) can be determined:

$$\alpha_H = arc \cos \frac{v_L(\alpha = 0)}{v_{L\max}} \tag{7}$$

The contact slewing angles on the left/right-hand side (α_J and α_B) can be calculated for the required side slope as the sizes of the block and the slices are known. The minimum value of the depth of cut is determined by the condition that the slices must be cut in full width, without reducing the winning efficiency. So the following condition must be fulfilled:

$$\alpha_j \text{ } és \text{ } \alpha_B \leq \alpha_H \tag{8}$$

This is how the depth of cut is chosen according to the swinging speed limit.

The selection of the optimal depth of cut can be influenced by the construction parameters of the winning tool (cutting tooth, bucket). This requires additional examinations. We do not deal with this issue in the present paper.

Step 5: For the chosen parameters, the power demand of the swinging must be inspected. In continuous operation, it must be smaller than the nominal power demand of the turn motors. This may be a topic of further examinations and papers.

It is easier to follow the above steps if we represent the relation of the examined parameters in diagrams. Using these diagrams, we can easily determine the range of optimal values. Figures 2-5 show the diagrams calculated with the data of the bucket-wheel excavator marked MT-6 operating in the surface mine of Visonta.

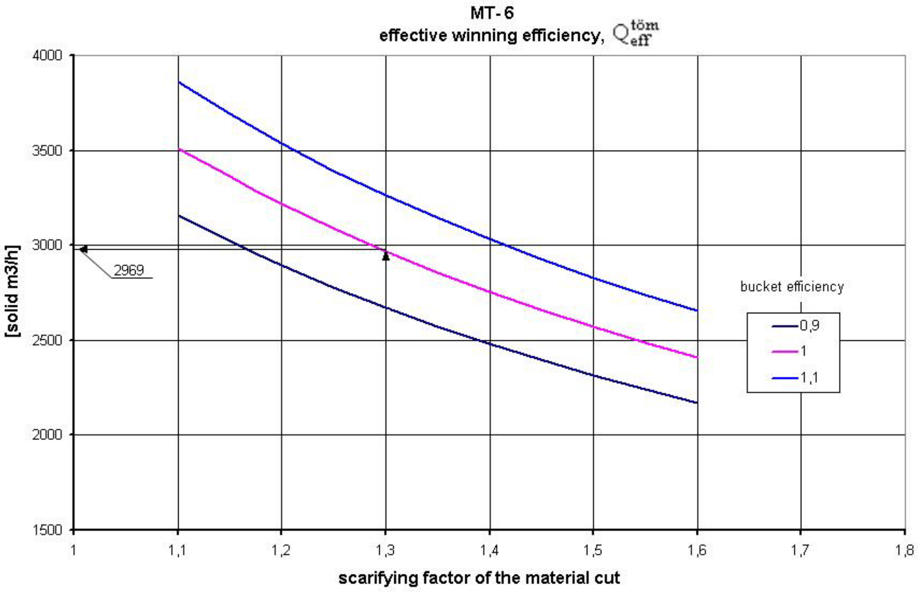

Fig. 2. Variation of capacity with scarifying factor of the material cut

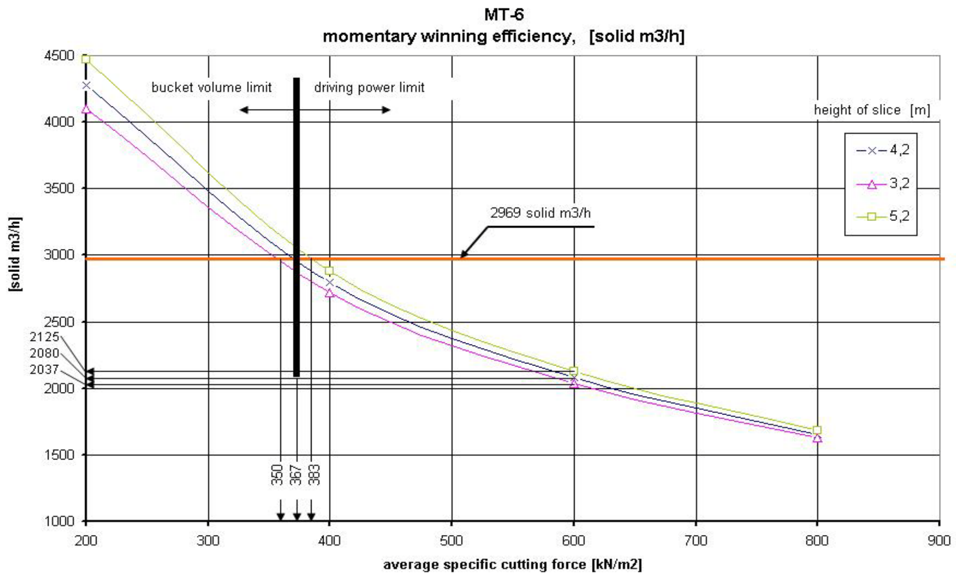

Fig. 3. Variation of capacity with average specific cutting force

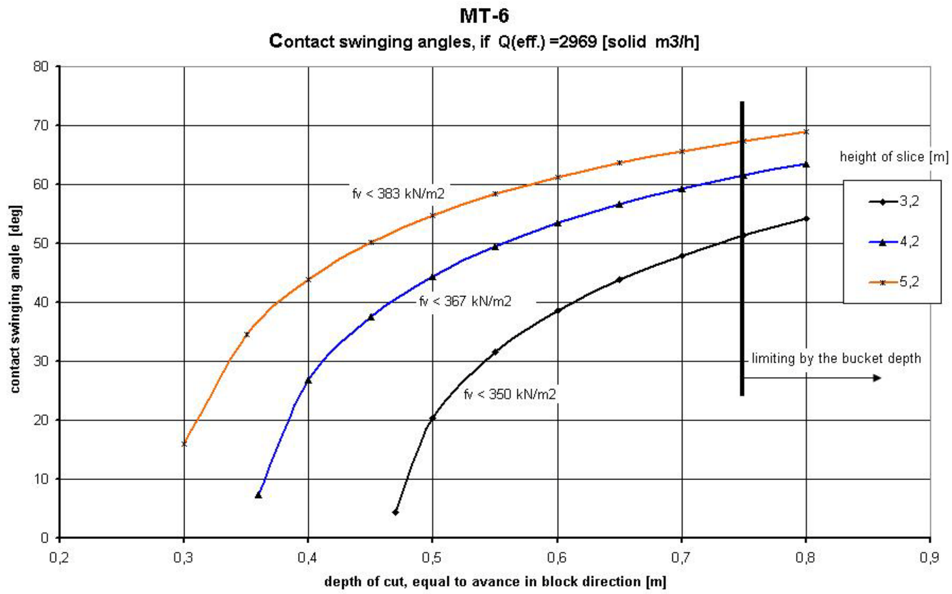

Fig. 4. Variation of contact swinging angle with depth of cut, if Q(eff.) = 2969 solid m^3/h

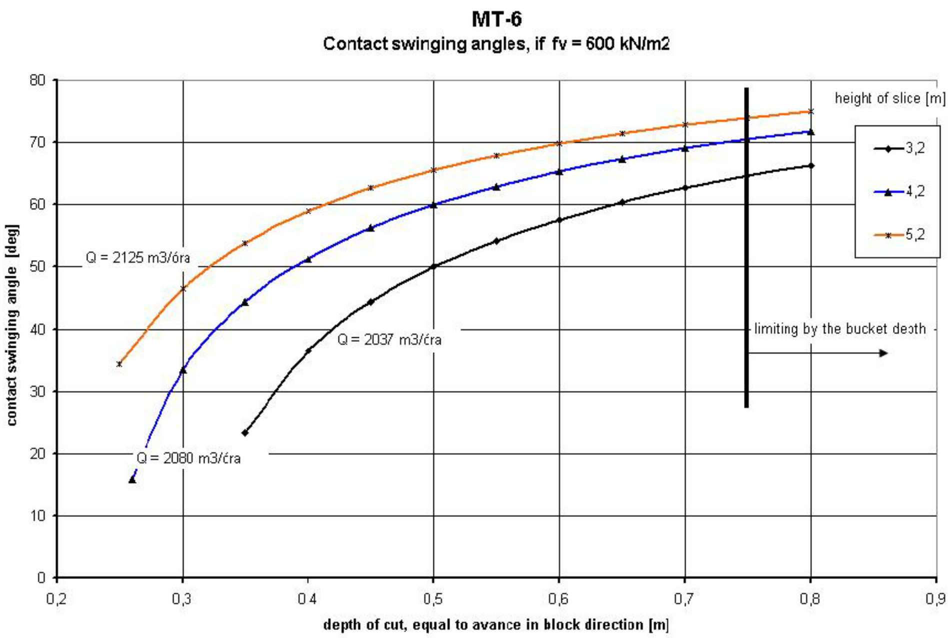

Fig. 5. Variation of contact swinging angle with depth of cut, if fv = 600 kN/m^2

4. INTERPRETATION AND CALCULATION OF THE CUTTING PARAMETERS

Hereinafter we give the interpretation and calculation of the parameters used in the steps under item 3.

Cutting parameters:

a) depth of cut (t),

b) chip width (b),

c) chip cross-section (A_{forg})

The height of cut of the bucket-wheel is identical with the height of the slice to be cut:

$$M = h. \tag{9}$$

We interpret the cutting parameters according to Figure 6, in the vertical and horizontal main cutting planes.

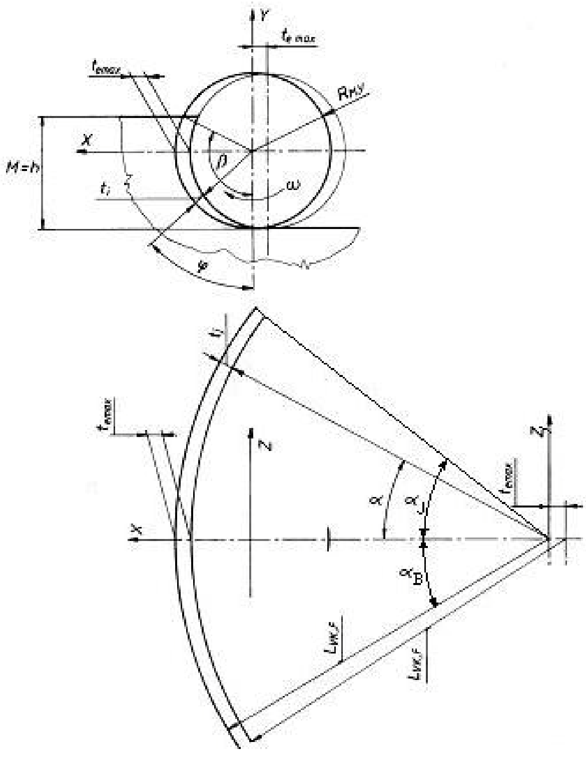

Fig. 6. The cutting parameters

ad a) The maximum depth of cut $t_{e\max}$ is identical with the magnitude of advance in block direction and can be measured in the line of intersection of the main cutting planes.

In the vertical main cutting plane, the depth of cut changes according to the function

$$t_i \cong t_{e\max} \cdot \sin\varphi \tag{10}$$

where φ is the slewing angle measured from the Y-axis. In the horizontal main cutting plane, the depth of cut changes according to the function

$$t_j \cong t_{e\max} \cdot \cos\alpha \tag{11}$$

where α is the jib slewing angle measured from the vertical main cutting plane on the right/left-hand side. In an arbitrary (φ, α) bucket position, the depth of cut is

$$t_{i,j} \cong t_{e\max} \cdot \sin\varphi \cdot \cos\alpha \tag{12}$$

ad b) We interpret it in the horizontal main cutting plane. Its magnitude is identical with the distance of the cutting edge centres of the successive buckets. For an arbitrary jib slewing angle α:

$$b\,(\alpha) = v_L\,(\alpha) \cdot \Delta T_c = \frac{v_L(\alpha)}{n_ü} \tag{13}$$

ad c) Using the above parameters, the cross-section of the chip being cut, in an arbitrary bucket position, is:

$$A_{forg}\,(\varphi, \alpha) = t \cdot b \tag{14}$$

Theoretical winning efficiency (It is the basis for calculating the winning efficiencies)

$$Q_{elm}^{laza} = V_M \cdot n_ü \text{, loose m}^3\text{/h} \tag{15}$$

The winning efficiency can be calculated from the nominal volume of the bucket and the number of discharges. This is the maximum efficiency belonging to the nominal bucket efficiency ($k_{tölt}$ = 1), expressed in loose material volume. 50 % of the volume of the annular space is usually added to the volume of the bucket.

Effective winning efficiency:

$$Q_{eff}^{töm} = Q_{elm}^{laza} \cdot \frac{k_{tölt}}{k_{laza}} \text{, solid m}^3\text{/h} \tag{16}$$

This is the highest achievable technical efficiency.

The bucket efficiency ($k_{tölt}$) may be greater than 1 if allowed by the properties of the material cut, but it may be smaller, too, if restricting conditions occur at winning.

The scarifying factor of the material cut (k_{laz}) can be determined by sampling the material. Its value varies between 1.1 and 1.6.

Momentary winning efficiency. It is calculated from the solid volume of the chip cut by the bucket in one winning (cutting) cycle.

$$Q_{jöv}^{töm} = V_{forg}^{töm} \cdot n_{ü}\text{, solid m}^3\text{/h} \tag{17}$$

Determining the chip volume from the cutting parameters, the winning efficiency is:

$$Q_{jöv}^{töm}(\alpha) = h \cdot t_e \cdot \cos\alpha \;.\; v_L(\alpha)\text{, solid m}^3\text{/h} \tag{18}$$

It can be seen from the relationships that the winning efficiency can be kept at constant value by increasing the swinging speed from the value for α=0, according to the cosine of the slewing angle. This is called “cosine” control. The swinging speed has a maximum value typical of the machine and the winning of the given slice. After reaching this value, the winning efficiency cannot be kept at constant value. For this speed, one can calculate a contact swinging angle (α_H) above which the efficiency will decrease.

$$\alpha_H = arc\cos\frac{v_L(\alpha = 0)}{v_{L\max}} \tag{19}$$

Designing the technology, one has to choose the chip and block parameters in such a way as to minimise the winning outside the limit angle.

Average power demand of the bucket-wheel drive used for winning, P_J :

$$P_J = k_K \cdot f_v \cdot Q_{jöv}^{töm}\text{, kW} \tag{20}$$

Average power demand of material lifting, increased with additional resistances, P_{EM}:

$$P_{EM} = \frac{1}{\eta_{em}} \cdot h_{em} \cdot \rho_t \cdot g \cdot Q_{jöv}^{töm} \tag{21}$$

where η_{em} is the lifting efficiency. Its value can be chosen between 0.5 and 0.7.

Using these values, the average power demand of the bucket-wheel drive, $\overline{P}_M$:

$$\overline{P}_M = \frac{P_J + P_{EM}}{\eta_h} \tag{22}$$

The average power demand of jib swinging resulting from winning, P_F :

$$P_F(\alpha) = \frac{k_k}{k_{F,R}} \cdot f_v \cdot Q_{jöv}^{töm} \cdot \frac{v_L^V(\alpha = 0)}{v_{K,V}} \cdot \frac{\cos\alpha}{\cos^2\alpha + \frac{b^v(\alpha = 0)}{\bar{t}_i(\alpha = 0)}} \tag{23}$$

Table 1. **List of notations**

$\overline{A}_{forg}$	average chip cross-section [m^2]
b	chip width [m]
f_v	average specific cutting force [N/m^2]
h	height of slice [m]
$k_{F,R}$	ratio of average cutting and pressing forces
k_K	wear coefficient of tool
k_{laz}	scarifying factor of the material cut
$k_{tölt}$	bucket efficiency
λ	length of path till halt of a jammed bucket-wheel [m]
$\overline{P}_F$	average power requirement of boom slewing due to cutting [kW]
$\overline{P}_J$	average power requirement of cutting [kW]
$\overline{P}_M$	average power requirement of bucket-wheel drive [kW]
$P_{M,mot}$	nominal capacity of bucket-wheel driving engine [kW]
P_{EM}	average power demand of material lifting [kW]
V_M	bucket volume
$V_{forg}^{töm}$	chip volume
$n_ü$	dumping number [count/rev.]
$Q_{eff}^{töm}$	effective winning efficiency [solid m^3/h]
Q_{elm}^{laza}	theoretical winning efficiency, determined from nominal bucket volume [loose m^3/h]
$Q_{jöv}^{töm}$	momentary winning efficiency [solid m^3/h]
t_{emax}	maximum depth of cut, equal to advance in block direction [m]
$\bar{t}_i$	average depth of cut in the ‘vertical’ main cutting plane [m]
$v_{K,V}$	circumferential speed of bucket-wheel at the cutting edge centre [m/s], i.e., the cutting speed of the bucket
v_L	swinging speed of bucket-wheel [m/s]
α	slewing angle from the ‘vertical’ main cutting plane [^{o} or rad]
α_B	contact slewing angle on the left-hand side [^{o} or rad]
α_J	contact slewing angle on the right-hand side [^{o} or rad]
α_H	contact swinging angle [^{o} or rad]
η_{em}	lifting efficiency
η_h	driving unit efficiency
ρ_t	solid density of material cut[kg/m^3]
$v_{jöv}$	cutting speed [m/s],
M	height of the slice