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DETERMINATION OF THE OPERATING POWER OF THE ROTOR OF THE ERC-1400 TYPE BUCKET WHEEL EXCAVATOR USING NUMERICAL METHODS

Florin Dumitru POPESCU, Andrei ANDRAȘ, Ildiko KERTESZ (BRÎNAȘ)

Abstract: In the paper, a new approach – using a virtual model and numerical method – is presented, to determine the operating power of the rotor of the ERC1400 model bucket wheel excavator (BWEs) used in the open-pit lignite mines of Oltenia region in Romania. The developed method enables more functional analyses of the subsystems of the BWEs, to reduce the specific energy consumption during excavation, to improve the cutting and loading system, and thus the excavation capacity. The authors created a model equipped with 18 buckets using SolidWorks, simulated the weight of excavated material, inertias, and cutting resistance, in order to determine the operating power variation, with more accurate results as compared to the analytical calculations usually used.
Keywords: *Bucket-wheel excavator, operating power, energy balance, rotor, ERC-1400, simulation, cutting force, excavation.*

1. INTRODUCTION

According to [11] and [12], a bucket-wheel excavator (BWE) is a complex mechanical equipment performing continuous digging, used in surface mining for the excavation of overburden material or coal, using a layout of buckets installed on the periphery of a rotating vertical wheel (rotor). It also performs the transport of the discharged material, using the wheel boom conveyor, to the main conveyor transport system.

The actual working tool is the bucket wheel (rotor), attached to a boom. It performs a rotation in the vertical plane, a pivoting movement in the horizontal plane and it can also be vertically raised or lowered using hoisting ropes attached to the boom [14]. Using numerical methods, we determine in the paper the operating power of the rotor.

Authors of [3] and [4] state that the scope of using virtual models for the analysis of the behaviour of BWE subsystems and components is to reduce the specific energy consumption during excavation and to improve the cutting and loading system and thus the excavation capacity, and at the same time maintain the same installed power for the operation of the rotor.

In [6] it is found that optimization of mining machines activity is possible with the purpose of achieving the most favorable working conditions.

2. THE DEFINITION AND CALCULATION OF THE EXCAVATION PARAMETERS

The proposed approach to determine the operating power of the rotor has been applied to the ERC1400 model BWE [15]. This is the most commonly used model in the open-pit lignite mines of Oltenia region in Romania.

The dimensional characteristics of the positioning of the rotor and the slewing mechanism are shown in figures 1 and 2. The description of the notations is: L_{sp} – the distance between the rotation axis of the boom and the pivoting axis of the upper platform; L_p – the pivoting length of the boom; H_{sp} – the distance between the center of the rotor and the lowest part of the boom; H_s – the height of the rotation axis of the boom compared to the working level of the excavator; B_r – the distance between the center of the rotor and the vertical symmetry plane of the boom; δ – the angle between the longitudinal plane of the rotor and the pivoting axis of the boom

The excavator boom can be raised or lowered in the vertical plane around a rotation axis of the boom (figure 1). It also has a pivoting movement in the horizontal plane, around the rotation axis of the upper platform, with the pivoting speed V_p (figure 2).

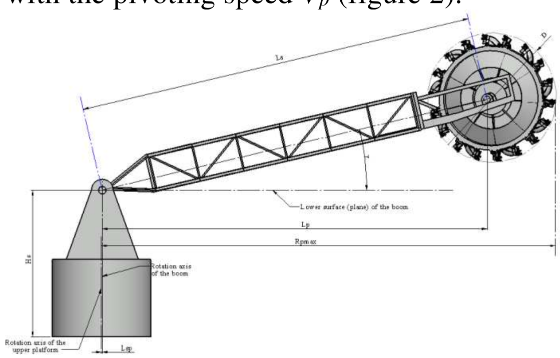

Fig.1. The dimensional characteristics of the boom and rotor system (side view)

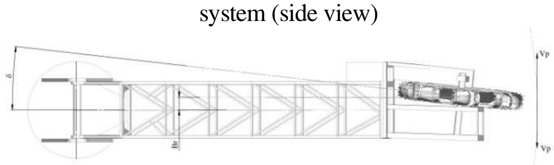

Fig.2. The dimensional characteristics of the boom and rotor system (top view)

The two planes of the raising-lowering and pivoting movements, because of technological limitations, are vertical and horizontal. There is a maximum limit of 3,5° ÷ 4,5° for both horizontal and vertical deviation [5], [7], [8].

The case of four terraces cut is shown in Figure 3. Since the pivoting radius in different for each terrace, the pivoting speed must be adjusted and correlated with the rotor position.

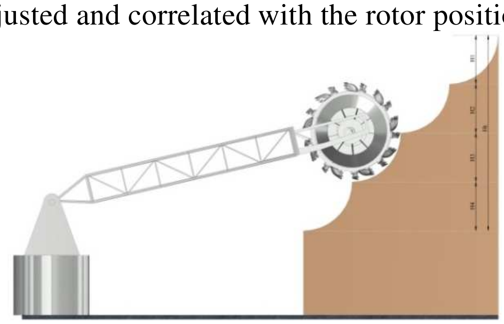

Fig.3. Excavation in four terraces

3. THEORETICAL ASPECTS OF THE FORCES, ENERGY, AND POWER

During excavation, there are two major components of the energy consumption of the rotor: the energy needed for the actual excavation of material and the energy needed for lifting with the buckets that material [1], [7]-[9].

The energy needed for the excavation is predominant and represents 60 ÷ 90% of the total energy necessary for driving the bucket wheel. Determining the power and energy required for operation in various scenarios is important for new BWE design, improvements of cutting and loading subsystems for existing BWE, or the selection of the right BWE for a certain application from more models.

The calculation of the power required for cutting with BWEs can focus on: determining the dependence of the power - for a given excavator - on the parameters of its working regime; energy optimization by achieving an imposed cutting capacity with minimal energy consumption; determination of the dependence of the power absorbed by the cutting – loading system on the cutting capacity and the pivoting speed in the face.

In case of BWEs, the force parameters refer to the forces acting on the buckets (F_x - the cutting force acting on a tangent direction to the trajectory of the bucket, F_y - the penetration force acting on a normal direction to the trajectory of the bucket, and F_z - the lateral force acting on a binormal direction to the bucket trajectory) and the forces exerted on the rotor (F_{xR} - the resultant cutting force, F_{yR} - the resultant penetration force, and F_{zR} - the resultant lateral force).

The energy parameters concern P_{ex} - the power needed for excavation, P_r - the power needed for lifting the material, and P_p - the power needed for pivoting the upper structure (the boom and the rotor). These parameters are determined by time and the dislocated chip characteristics.

The operating power required to drive the rotor is:

$$P = \frac{P_{ex} + P_r}{\eta_t} \tag{1}$$

where η_t is the efficiency of the bucket wheel gearbox [8], [12], [13].

Thus, it becomes:

$$P = \frac{1}{\Delta t \cdot \eta_t} Q_t \left[\frac{k_{uz} \cdot K_e}{k_a} + \frac{1}{\eta_r} \left(D - \frac{H}{2} - \frac{2}{3} h_c \right) \rho_a \cdot g \right] \quad (2)$$

Where Q_t is the theoretical excavation capacity (3280 m^3/h); η_t is the bucket wheel gearbox efficiency (0,85); k_{uz} is the wear degree of the teeth (1,2); K_e is the specific cutting resistance (60 N/cm^2); k_a is the loosening coefficient (1,35); η_t is the bucket loading-discharging efficiency (0,6...0,7); D is the cutting diameter of the rotor (11,5 m); H is the height of the terrace (7,5 m); h_c is the active height of the bucket (0,84 m); ρ_a is the loose rock density (1,3 – 2 t/m^3).

Calculating equation (2), we obtain the operating power of the rotor, 314 kW.

Past research and in-situ measurements done during excavation by our department, for the same parameters and BWE, pointed to a medium measured power of 298 kW [2], [15].

4. A NUMERICAL METHOD FOR THE DETERMINATION OF THE OPERATING POWER OF THE ROTOR

The theoretical method proposed in section 3, based on mathematical equations with approximations of certain coefficients, can sometimes provide erroneous results.

To compare the results, and also avoid flawed values, a new approach is proposed. A SolidWorks model of a BWE rotor equipped with 18 buckets (9 cutting – loading and 9 cutting buckets) was created in SolidWorks for analysis. The model and the application points for the resultant forces acting on the buckets and rotor is shown in figure 4.

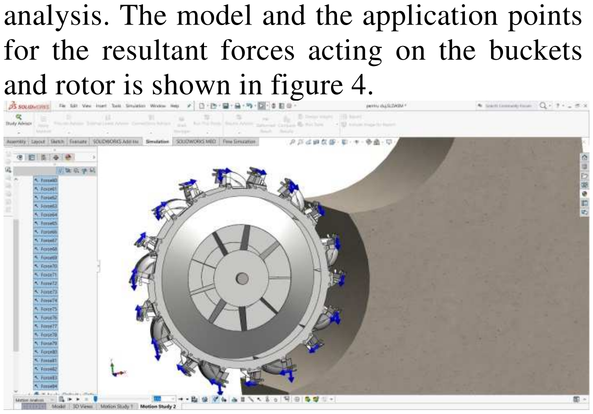

Fig.4. Screenshot of the rotor model and the forces considered during excavation

Three types of forces were considered: the resultant forces produced by the cutting resistance of the rock (for the buckets cutting at a certain moment), the forces exerted by the weight of the excavated material inside the buckets, and the inertia forces produced by discharging the buckets [11].

The diagram of the variation in time of the forces exerted by the weight of the excavated material on the first cutting-loading bucket is shown in figure 5. The ascending segment (first part of the diagram), represents the material as it is cut and it fills the buckets. The horizontal segment represents the lifting of the material and the movement to the discharge point. The descending segment (last part of the diagram) represents the discharge of the bucket onto the boom conveyor.

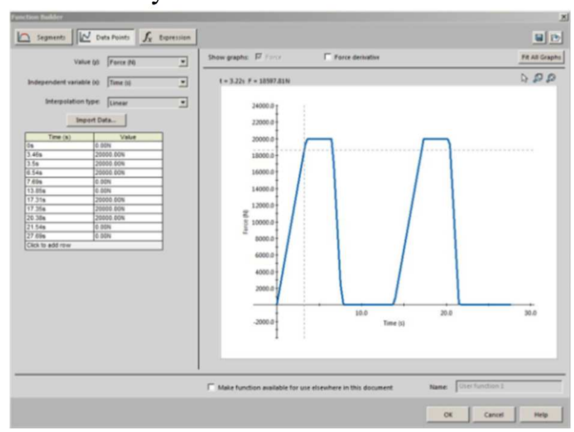

Fig.5. Time variation diagram of forces acting on a cutting-loading bucket

The simulation was run for a period of two complete rotations. Between two successive cuts of the same bucket, the offset time seen on the diagram from Figure 5 depends on the speed of the rotor.

The speed used in the simulation is 4.33 rpm, corresponding to a cutting frequency of 39 buckets/min. The time interval between the cutting-loading period and the lifting period is imposed by the maximum excavation height. For the model, we considered H = 5.75 m.

The diagram of the variation in time of the cutting forces is presented in Figure 6. The cutting forces act on both the cutting-loading and cutting buckets. For the cutting buckets, it can be seen that the sections representing the lifting phase and the bucket discharging phase are missing in the diagram [15].

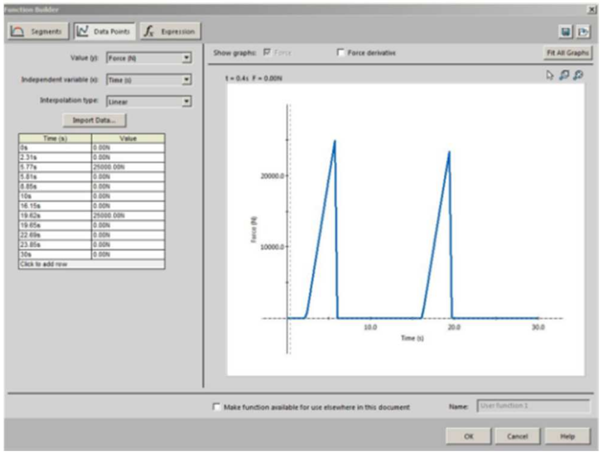

Fig.6. Time variation diagram of the cutting forces acting on a cutting bucket

The forces acting on all the buckets of the same type, for both types of buckets, are offset with a time interval of 1.54 seconds as shown in Figures 7, 8 (cutting-loading buckets), and 9 (cutting buckets).

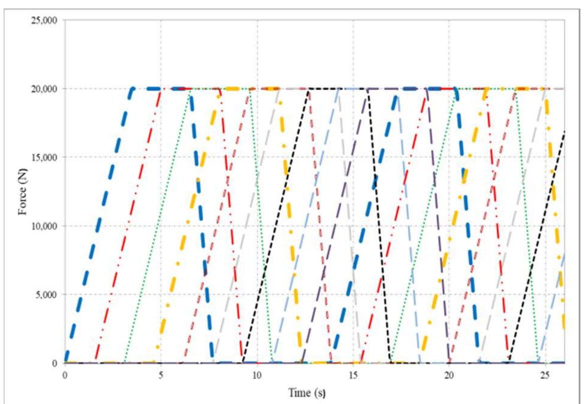

Fig.7. The variation in time and offset of the forces, exerted by the weight of the excavated material

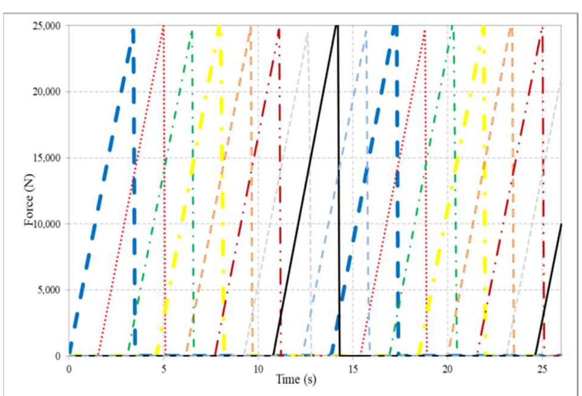

Fig.8. The variation in time and offset of the cutting forces exerted on the cutting-loading type buckets

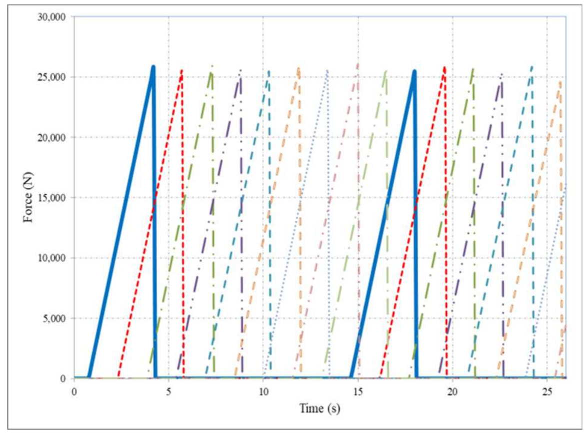

Fig.9. The variation in time and offset of the cutting forces exerted on the cutting buckets

By superposing these offset forces for two complete rotations (27.69 s), the variation in time of the total operating power is shown in Figure 10. The power varies between 202 kW and 276 kW, with a medium value of approximately 240 kW. Considering the efficiency of the transmission (0.85) the grid power demand was determined as being 240 / 0.85 = 281 kW. The value determined is close to both the in-situ measured values and the one determined using classic analytic calculations.

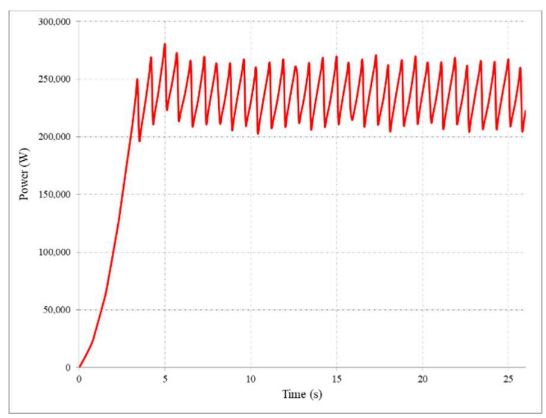

Fig.10. Variation in time of the total operating power for two complete rotations, considering both types of buckets.

This numeric determination compared to the classic method is more precise but it also shows the variation of the power. This is useful for the dynamic analysis of the BWE supporting structure.

The simulation model we presented also allows the use of the effects overlapping method, which is useful for the energy balance analysis of the excavation process.

The variation of operating power was determined, in the first phase, only for the forces exerted on the rotor by the weight of the excavated material (Figure 11). The power, in this case, varies between 88 kW and 94 kW, with a medium value of 91 kW. This is the power required to load the buckets and lift the material. The variation of power for just the cutting forces exerted on the rotor was determined in the second phase, for both types of buckets (cutting-loading and cutting). The power varies, in this case, between 110 kW and 175 kW with an average value of 142.4 kW (Figure 12).

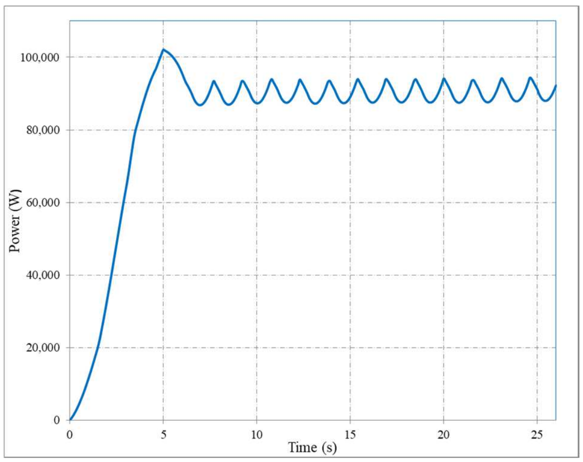

Fig.11. Variation of the operating power for the forces exerted on the rotor by the weight of the excavated material

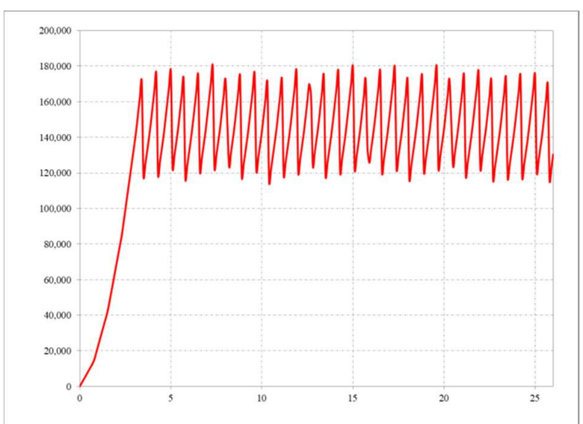

Fig.12. Variation of the operation power for the cutting forces exerted on the rotor

For the simulated model, the energy balance is shown in figure 13. The results show that 61% of the energy consumption is used for cutting the material and 39% is used for lifting the excavated material. The values are similar to past worldwide determination and technical literature, with 60 to 90% of the total energy used to drive the rotor being used for the cutting of material. [11].

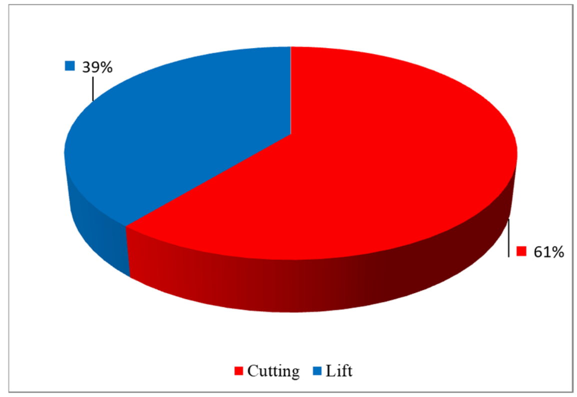

Fig.13. Energy balance of the excavation process

5. CONCLUSIONS

A new method – using a virtual model and numerical method – was developed, for the determination of the operation power of the rotor of an ERC1400 bucket wheel excavator.

This method can be used for further functional analyses of the subsystems and components of the BWEs, so as to reduce the specific energy consumption during excavation, to improve the cutting and loading system and thus the excavation capacity.

Three types of forces were considered in the simulation: the resultant forces produced by the cutting resistance of the rock (for the buckets cutting at a certain moment), the forces exerted by the weight of the excavated material inside the buckets and the inertia forces produced by discharging the buckets

The determined grid power demand using the new method, varies between 237 kW and 325 kW, the average value being of 281 kW. The value determined is close (approx. 5.7% difference) to the in-situ measured value (298 kW) and also to the one determined using classic analytic calculations (314 kW), the difference being reasonable as there is coefficient variation even for the same characteristics of the tool and the excavated rock.

Compared to the classic method, the presented method has higher accuracy, and it also shows the time variation of the power, which is useful in the dynamic analysis of the support structure of the excavator.

Since this method is based on numerical calculus methods, it applies to any type of rotor excavator and rock characteristics.

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Determinarea puterii de acționare a rotorului excavatorului tip ERC1400 folosind metode nmerice

Rezumat: În lucrare este prezentată o nouă abordare – folosind un model virtual și metode numerice – în vederea determinării puterii de acționare a rotorului excavatorului de tip ERC1400 utilizat în carierele de lignit din Oltenia. Metoda permite o analiză funcțională mai detaliată a organului de tăiere al excavatorului în scopul îmbunătățirii eficienței acestuia prin reducerea consumului specific de energie și a creșterii capacității de excavare.

Florin Dumitru POPESCU, PhD Eng. Habil., Professor, University of Petroșani, Department of Mechanical, Industrial and Transport Engineering, fpopescu@gmail,com, 0723719303, 20 Universității street, 332006, Petroșani, HD

Andrei ANDRAȘ, PhD Eng., Lecturer, University of Petroșani, Department of Mechanical, Industrial and Transport Engineering, andrei.andras@gmail.com, 0722366653, 20 Universității street, 332006, Petroșani, HD

Ildiko KERTESZ (BRÎNAȘ), PhD Eng., Assistant, University of Petroșani, Department of Mechanical, Industrial and Transport Engineering, kerteszildiko@ymail.com, 0726703067, 20 Universității street, 332006, Petroșani, HD