

SIMULATION AND MODELLING OF THE FORCES ACTING ON THE ROTOR SHAFT OF BWES, IN ORDER TO IMPROVE THE QUALITY OF THE CUTTING PROCESS

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Abstract: BWEs used in open pit coal mining are subjected to excessive loads during cutting because of the interaction between the working face and the bucket wheel's components. High loads and unexpected shocks produce downtimes, increased wear, or severe damage of the BWE components or operational subsystems, leading to increased energy consumption, lower production rate and, finally, increased mining costs. A study of the forces acting on the shaft of the bucket wheel was conducted, using computerised modelling and simulation, in order to reduce the mentioned issues and improve the quality of the excavation process.

Keywords: BWE, Rotor shaft, Cutting process, Simulation, Forces

1. INTRODUCTION

The bucket wheel excavator (BWE) is a machine with continuous operation which cuts the rock with the help of the buckets installed on the rotor, performing at the same time the transfer of the excavated material to the main conveyor, with the help of the conveyor belts installed on its boom. The operating equipment is the rotor (bucket wheel) which performs a rotation movement in vertical plane and, with the help of the boom, a horizontal pivoting movement and a vertical ascendant – descendent movement. In this paper we present a modality of determining the

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operation power of an excavator rotor using numerical methods. The aim of approaching some virtual models which allow the analysis of the operation of some components of the rotor excavator resides in the improvement of the cutting – loading system, the reduction of the specific energy consumption during the cutting operations while maintaining the installed power for the operation of the rotor and the increase in the excavation capacity, respectively the degree of intensive use of the excavator..

2. DEFINITION AND CALCULUS OF THE EXCAVATION PARAMETERS

The method proposed for the calculus of the operation power of the rotor has been applied to a model EsRc 1400 excavator. This type of excavator is used in the lignite mine pits in the coal fields in Oltenia.

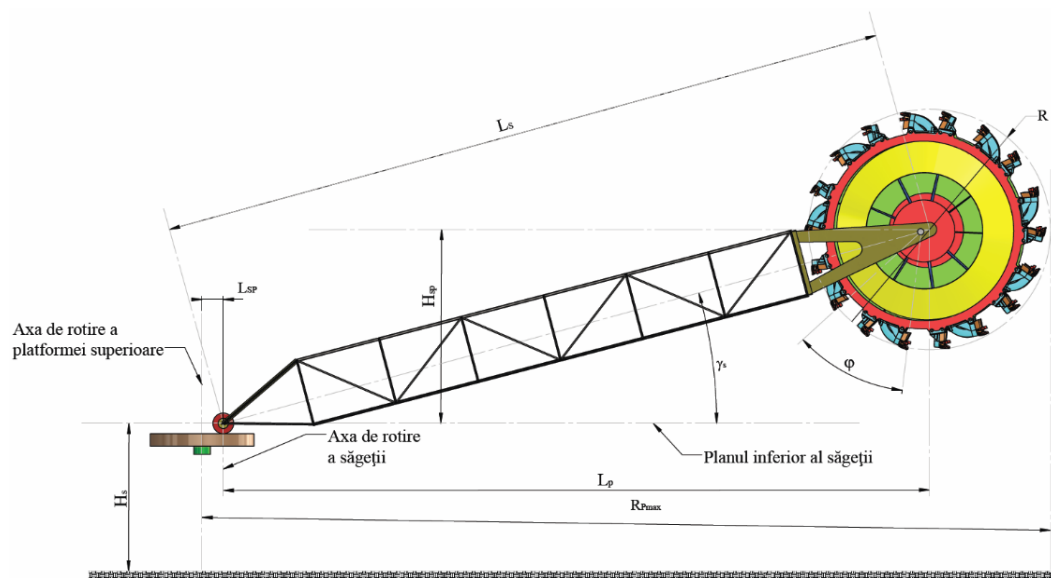


Fig.1 The geometric characteristics of the arm - rotor system, side view

The geometric characteristics regarding the positioning of the rotor and the rotation mechanism are presented in figure 1 where the notations employed carry the following significance:

- H_s – the height of the rotation axis of the boom as against the operating level of the excavator;
- L_{sp} – the distance between the rotation axis of the boom and the rotation axis of the upper platform;
- L_p – the pivot length of the boom;
- H_{sp} – the distance between the rotation center of the rotor and the lower surface of the boom;

- H_{sp} – the distance between the rotation center of the rotor and the symmetry vertical plan of the boom;
- δ – the angle between the longitudinal axis of the rotor and the pivoting axis of the boom.

The arm of the excavator performs in vertical plane an ascendant and descendent movement around the rotation axis of the boom (figure 1). Horizontally, the rotation movement occurs around the rotation axis of the upper platform with the pivoting speed V_p (figure 2). From a technological and also energetic point of view, the plans in which the two rotations appear (ascendance – descendance and pivoting) must be vertical, respectively, horizontal. The vertical and horizontal deviation must not exceed 3,50 – 4,50.

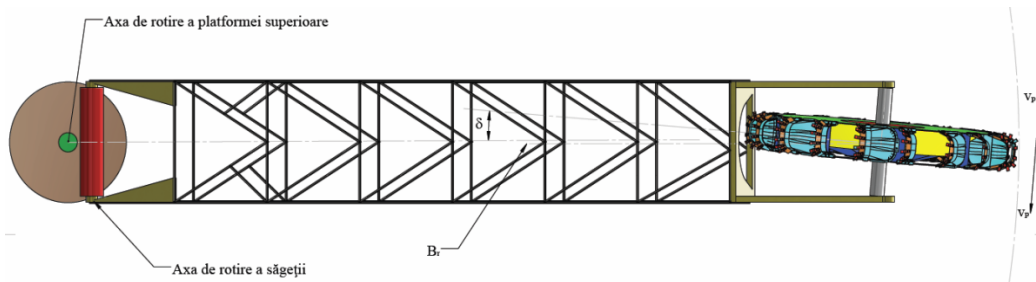


Fig.1 The geometric characteristics of the arm - rotor system, view from above

Figure 3 illustrates the case of the excavation of four slices, numbered 1, 2, 3 and 4. For each of these slices, the pivoting radius is modified. For this reason, it is necessary to correlate the pivoting speed with the position of the rotor.

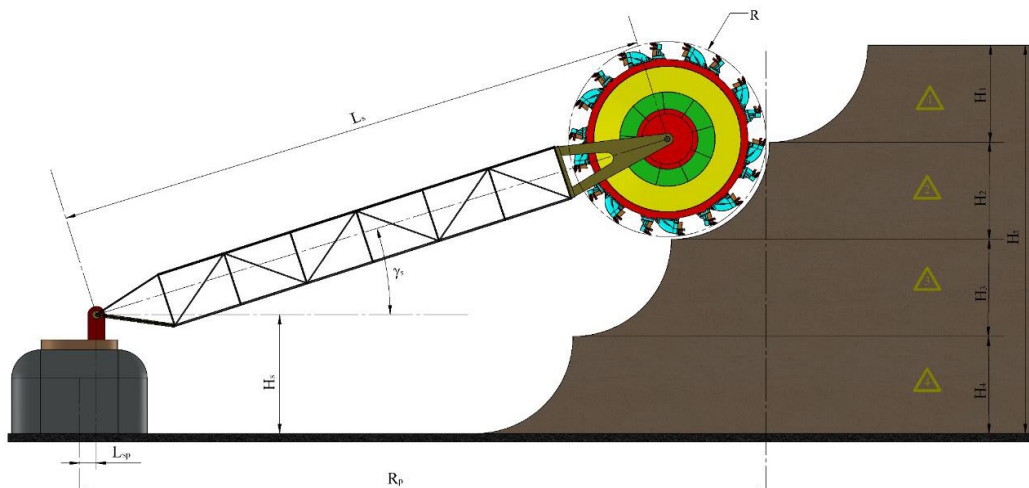


Fig.3 Excavation of slices

3. CALCULUS OF FORCE AND ENERGETIC CHARACTERISTICS

During the excavation process, the energy consumption at the level of the bucket wheel has two major components:

- the energy necessary for cutting the material to be excavated;
- the energy necessary for lifting the loose material resulted from cutting with the help of the buckets.

Between the two of the components presented above, the energy necessary for cutting the material is predominant, representing 60 ... 90% of the energy necessary for operating the bucket wheel.

Determining the energy and power necessary for operating the bucket wheel under certain functioning circumstances is essential for:

- the selection of excavators from an existent lot;
- the design of new excavators;
- the design of the new cutting – loading systems for the existent excavators.

The calculus of the power necessary for cutting with rotor excavators can aim at:

- determining the dependence of the power on the parameters of the operating regime for a given excavator;
- optimizing the energetic regime by accomplishing a cutting capacity at minimum energy consumption;
- determining the dependence of the power absorbed by the cutting – loading system on the cutting capacity, respectively the pivoting speed in the working front.

For the BWEs the force characteristics refer to:

- the forces which act on the bucket represented by:
 - the cutting force F_x which operates according to a direction tangent to the trajectory of the bucket;
 - the penetration force F_y which operates according to a normal direction to the trajectory of the bucket;
 - the lateral force F_z which operates according to a binormal direction to the trajectory of the bucket.
- the forces which act on the rotor are represented by:
 - the resultant cutting force F_{xR} ;
 - the resultant penetration force F_{yR} ;
 - the resultant lateral force F_{zR} .

The energetic characteristics refer to:

- the power necessary for excavation P_{ex} ;
- the power necessary for lifting the material P_r ;
- the power necessary to pivot the upper platform of the excavator, the boom and the rotor P_p .

The force and energy parameters depend on time and the characteristics of the dislocated chip. In practice, average values are employed so that we have:

According to the above information, the power necessary to drive the rotor will display the expression:

$$P = \frac{P_{ex} + P_r}{\eta_t} \quad (1)$$

where η_t represents the efficiency of the engine – bucket wheel transmission. Thus, the following results:

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

where:

Q_T - the theoretical excavation capacity (3280 m³/h);

D - the cutting diameter of the rotor (11,5 m);

H - the height of the bench (7,5 m);

k_{uz} - the wear degree of the teeth (1,2);

K_e - the specific cutting resistance (60 N/cm²);

k_a - loosening coefficient (1,35);

η_t - transmission efficiency (0,85);

h_c - the active height of the bucket (0,84 m);

ρ_a - loose rock density (1,3 – 2 t/m³).

After applying the relation (2), results a value of the operation power of the excavator rotor of 314 kW.

4. PROPOSING A METHOD OF DETERMINING THE OPERATION POWER OF THE ROTOR OF A BWE THROUGH MODELLING AND SIMULATION

The method presented in the previous section, based on mathematical relations and approximations is susceptible of errors leading to results which are not in accordance with reality. The development of the methods of modelling and simulation accomplished with packages of specialized integrated programs recorded lately offers the possibility of a holistic approach of the mechanical systems of the type presented in this paper, in which, the mechanical phenomena are solved intrinsically, without resorting to simplifying hypotheses which can affect the accuracy of the results.

In order to avoid the problems described previously, we have created the model of an excavator rotor using the SOLIDWORKS package. The analysed rotor is equipped with 9 cutting – loading buckets and 9 cutting buckets. A screenshot of the created model and the points of application of the resultant forces which operate the bucket are presented in figure 4. We considered the resultant forces produced by the cutting strength of the rock (for the buckets which are in the cutting process at a certain

moment), the forces resulted from the weight of the material in the buckets and the inertia forces which appear when the buckets are discarded (these are determined directly by the application we have used).

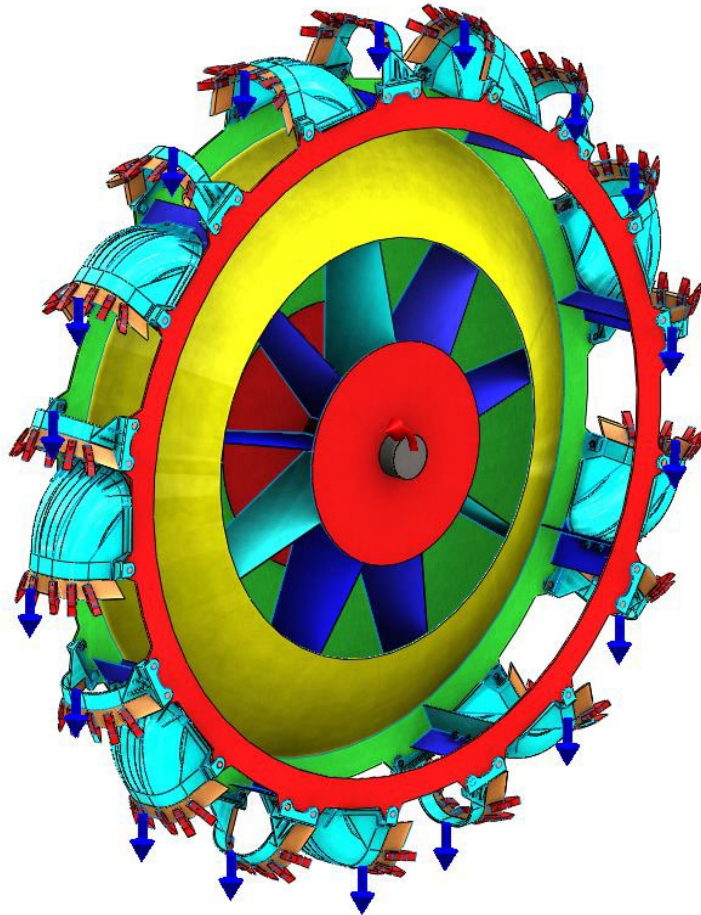


Fig.4 Screenshot of the bucket wheel

Figure 5 illustrates the diagram of time variation of the forces which drive the cutting – loading bucket.

Figure 6 presents the diagram of time variation of the forces which drive the cutting bucket. It can be noted that in the diagram in figure 6 the stages of lifting and discarding the bucket.

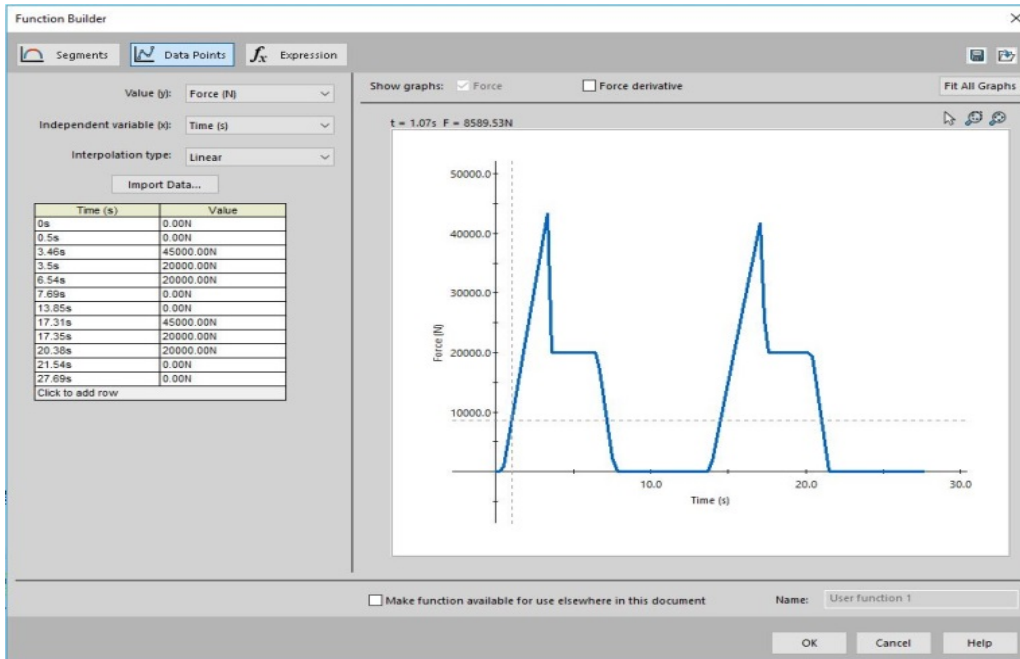


Fig.5 Diagram of time variation of the forces driving the cutting – loading bucket

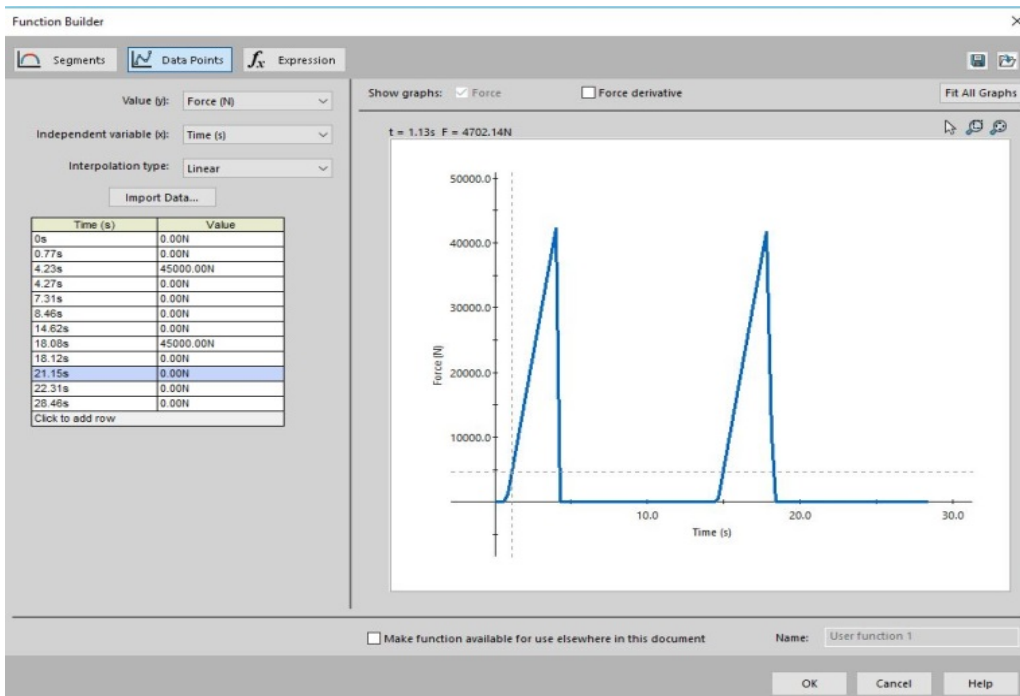


Fig.6 Diagram of time variation of the forces which drive a cutting bucket

The forces which drive the buckets are gapped with a short time interval of 1,54s, and the revolution of the rotor is 4,33 rot/min. Overlapping the forces which are gapped, we obtain for the duration of two complete rotations (27,69 s), the time variation of the operation power presented in figure 7.

This figure shows that the power fluctuates between the limits of 240 kW and 340 kW, the average value being of 290 kW. The fact that this value is close to the value obtained through the classic calculus method presented in the previous section is not surprising, as we have considered the same characteristics of the tool and the excavated rock. Unlike the classic method, the presented method displays, besides the high accuracy, the advantage of illustrating the time variation of the power which can be useful in the dynamic analysis of the support structure of the excavator.

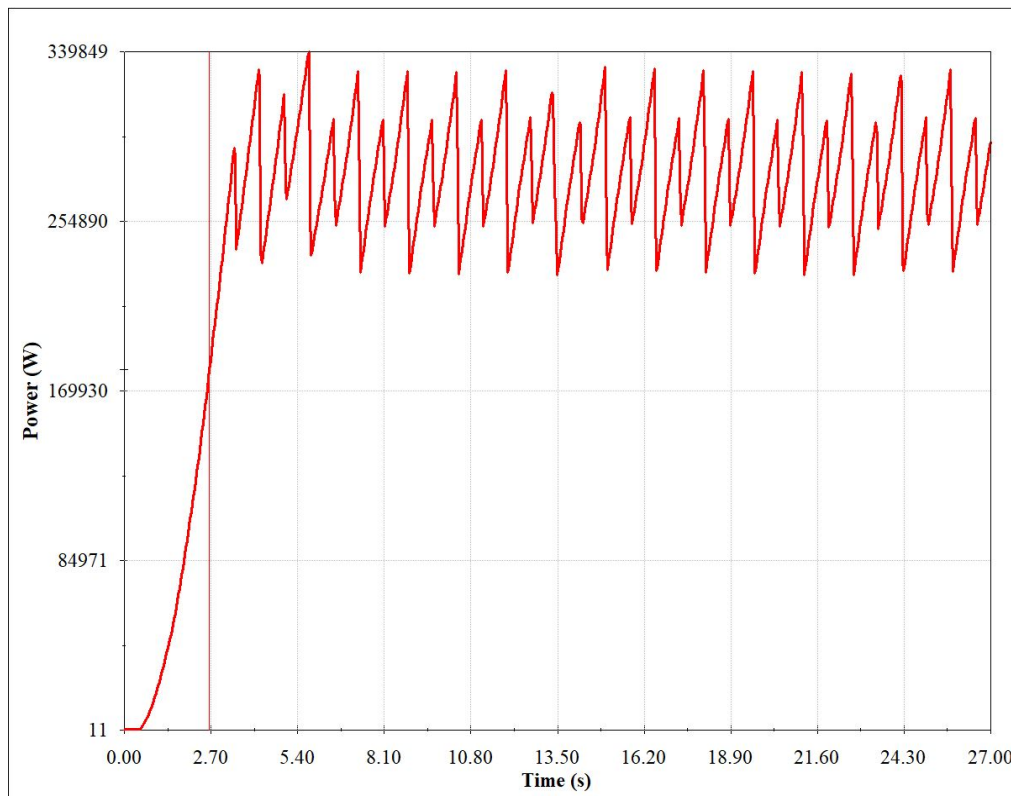


Fig.7 Time variation of the operating power

5. CONCLUSIONS

In this paper we propose a modality of determining the operation power of the rotor of an excavator through numerical methods.

The method is based on virtual models which allow the analysis of the functionality of the components of rotor excavators in order to improve the cutting –

loading system, to reduce the specific energy consumption during cutting while maintaining the minimum installed power of operation of the rotor and to increase the excavation capacity.

We have presented a model of a rotor created with the SOLIDWORKS package with 9 cutting – loading buckets and 9 cutting buckets.

We have considered the resultant forces produced by the rock cutting strength (for the buckets which are in the cutting process at a certain moment), the forces determined by the weight of the material in the buckets and the inertia forces which occur when the buckets are discarded (these have been determined directly by the application employed).

The power calculated with the presented method fluctuates between the limits of 240 kW and 340 kW, the average value being of 290 kW, close to the value of 314 kW obtained with the classic method, the difference being reasonable as it refers to the same characteristics of the tool and the excavated rock.

Unlike the classic method, the presented method displays, besides the higher accuracy, the advantage of illustrating the time variation of the power which can be useful in the dynamic analysis of the support structure of the excavator.

As the presented method is based on numerical calculus methods, it displays a feature of generality, being applicable to any type of rotor excavator and rock characteristics.

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REFERENCES

- [1]. **Kovacs, I., Nan, M.S., Andraş, I., Jula, D.,** *Stabilirea regimului extrem de funcționare a excavatoarelor cu roată portcupe.* Lucrările științifice ale Simpozionului Internațional „Universitaria ROPET 2002” 17-19 oct.2002 Petroșani – Inginerie mecanică
- [2]. **Kovacs, I., Nan, M.S., Andraş, I., Jula, D.,** *Study of the working regime of the bucket wheel excavators in the conditions of Romanian open pit lignite mines,* 8th WSEAS International Conference on Simulation, Modelling And Optimization (SMO '08), Santander, Cantabria, Spain, September 23-25, 2008
- [3]. **Kovacs, I., Andraş, I., Nan, M.S., Popescu, F.D.,** *Theoretical and experimental research regarding the determination of non-homogeneous materials mechanical cutting characteristics,* 8th WSEAS International Conference On Simulation, Modelling And Optimization (SMO '08) Santander, Cantabria, Spain, September 23-25, 2008

- [4]. **Nan, M.S.**, *Parametrii procesului de excavare la excavatoarele cu rotor*, Editura Universitas, Petroşani, 2007
- [5]. **Raaz, V.**, *Optimierung der maschinen- mid Verfahrenrechnischen Parameter von Schaufelradbagger für einen abbau von harteren Materialien im Tagebau*. Braunkohle in Europa: Innovationen für die Zukunft; 1.Internationale Konferenz, 29.März bis 1.Aprili 2000. in Freiberg, Tagungsband
- [6]. **Sümeği, L.**, *Külfejtési marótárcsás kotrógépek jövesztő szerkezetének elméleti vizsgálata és fejlesztése*. Doktori értekezés, Miskolcy Egyetem, 2002