SIMULATION OF THE EXCAVATION PROCESS DYNAMICS OF A HYDRAULIC EXCAVATOR USING SOLIDWORKS

BOGDAN IOAN MARC [1], STELA DINESCU [2], DANIELA–IOANA BUDILICĂ (ANDREI) [3]

Abstract: The essential feature of single bucket hydraulic excavators used in mining and construction, is that their performance, such as work space, technological forces, cutting and loading capacity, are closely related to the excavator structure and operation, kinematics and dynamics of the bucket-arm mechanism, which can be studied based on the theory of manipulators, adapted to build a virtual model of such a machine. For the simulation and study of the dynamic, a model was built for the excavator arm-bucket for the Hyundai R30Z-9AK mini excavator model, using SOLIDWORKS® software. On this model, we simulated the dynamics of the excavation, respectively we determined the power demand for different phases of the excavation process, taking into account for each component, the technological, inertia and resistance forces in each regime of work. Also an analysis of the load on the excavator bucket was performed, by calculating the von Mises stress from the beginning of the bucket movement to the end of the discharge, taking into account all the forces acting on it.

Keywords: excavator arm, power, force, bucket, von Mises strees, excavator

1. INTRODUCTION

In the mining industry, dislocation of the rocks represents the first stage - with a decisive role - in the process of extraction. Its role is to remove the rock fragments from the massif. The amount of dislocated rock depends on the parameters of the technological process and the rock must have a granulation that allows the loading and evacuation of dislocated fragments by different means of transport. The actual dislocation of material is determined by the interaction between the layer of material and a cutting tool. This interaction process produces a resultant force *R* acting on the

[1] *Ph.D. student, University of Petroşani, bogdanmarc94@yahoo.com*
[2] *Lecturer, Eng. Ph.D., University of Petroşani, dinescustela@yahoo.com*
[3] *Ph.D. student, University of Petroşani, danalupulescu@yahoo.com*

cutting tool. In the cutting plane this resultant forces resolves into two components: one is F_x which is a force acting along the cutting direction of the cutting tool, the other is F_y which is a force perpendicular to the cutting plane. Another lateral component, F_z also acts on the cutting tool, and corresponds to the lateral resistance of the material during dislocation (figure 1). The F_z component has a significant magnitude in the case of cutting organs performing a pivoting motion.

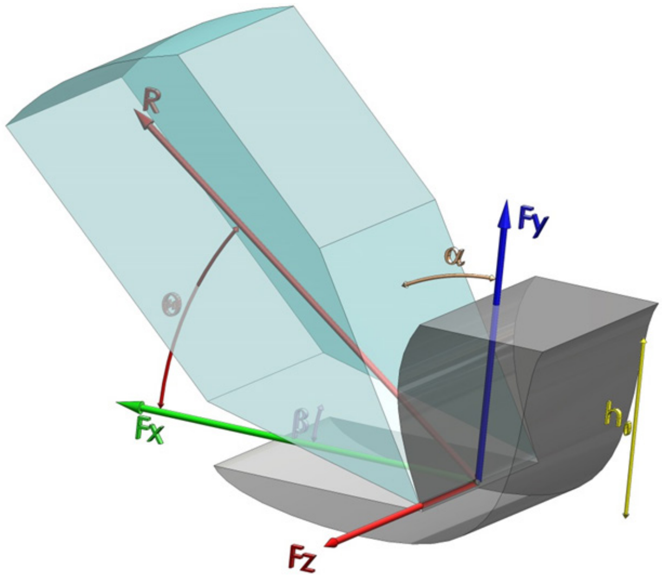


Fig. 1. Forces acting on the cutting tool

In the case of a cutting process done with the help of shearers, the way the chips detach from the mass and the volume of the chips are influenced, as it can be seen in Figures 2 and 3, by the depth of cut h_0 as well as the width b of the cutting tool edge. Another characteristic is the slope angle ψ, which represents the angle between the axis of the cutting tool and the direction of rupture of the chips.

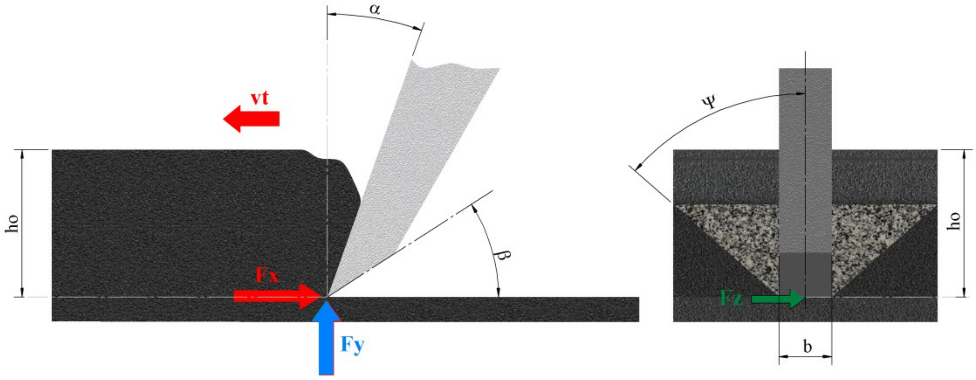


Fig. 2. Characteristics of cutting with chisel pick cutting tools

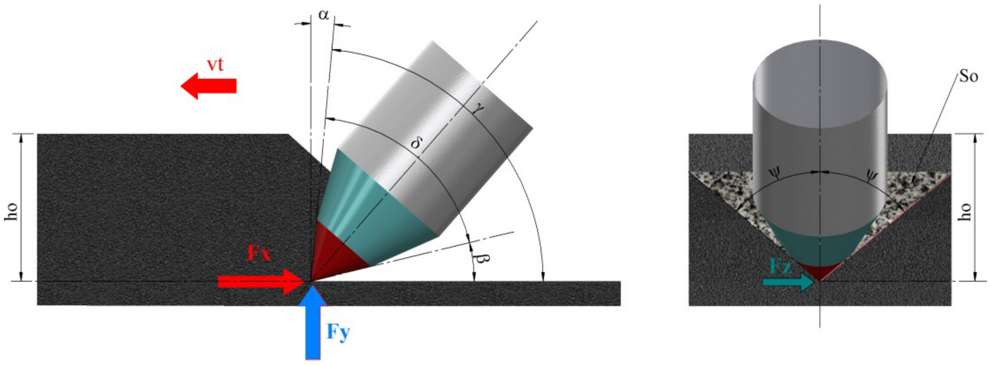


Fig. 2. Characteristics of cutting with conical picks

2. DETERMINATION OF THE POWER REQUIREMENT FOR EXCAVATION USING SIMULATION

Unlike bucket wheel excavators, where the slewing movement is part of the cutting, loading and unloading process, in the case of single bucket hydraulic excavators, pivoting has only a positioning role of transporting the material loaded into the bucket to its unloading point.

In order to determine the power required for the excavation process, using simulation and the mini-excavator arm model, two forces defined and added to the motion analysis as shown in Figure 4. Also, the material and its properties were defined for all components and parts, and gravity was taken into consideration as acting on the model.

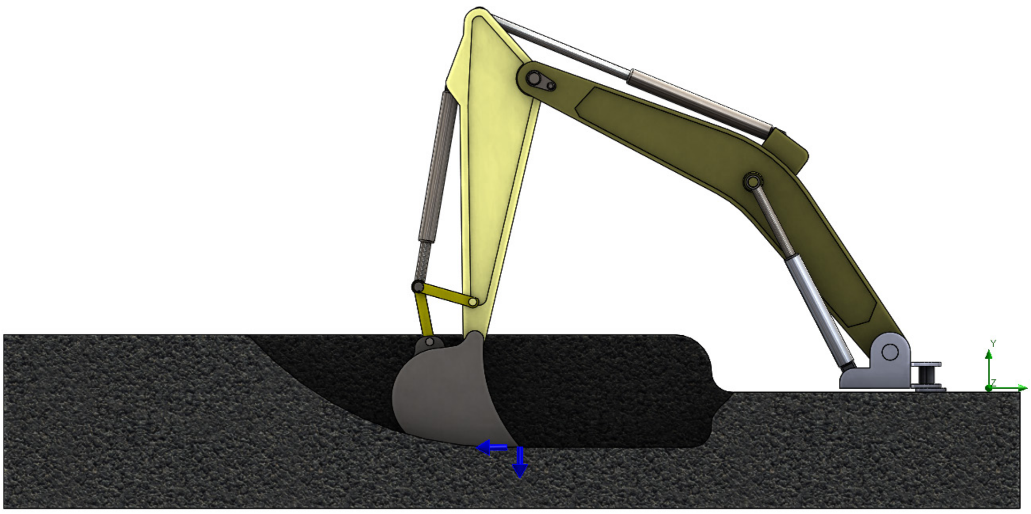
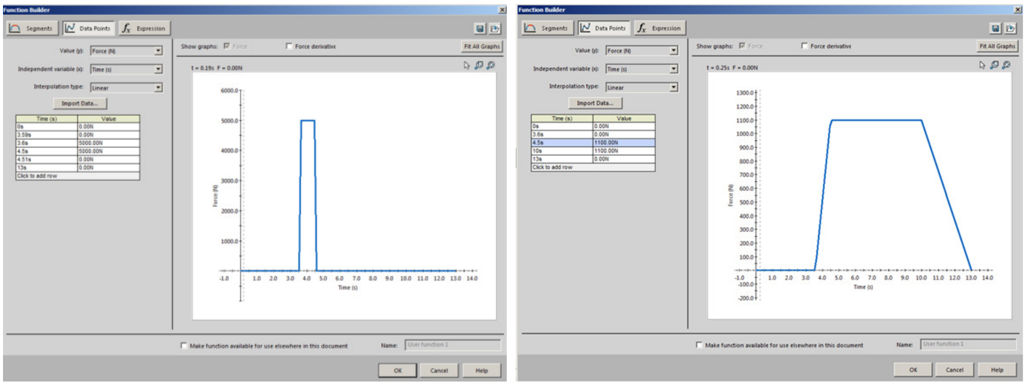


Fig. 4. Forces acting on the hydraulic excavator bucket

These forces act on the bucket of the mini excavator. The first force is the shear force required to cut the material which is collinear to the cutting direction of the teeth. The time variation of this force during the simulation period is represented by points as shown in Figure 5a. It was considered that the excavation is performed in wet soil, and the maximum value of the cutting force is 5000 N. According to the kinematics of the mini-excavator arm, the actual cutting takes place during the time interval 3.6…4.5 seconds, when the cutting force is constant. Outside this interval, the value of this force is zero.

The second force acting on the bucket corresponds to the weight of the excavated material. As in the case of the shear force, its variation as a function of time was represented by dots as shown in Figure 5b. In the time interval corresponding to the cutting, it was considered that this force has a linear increase, corresponding to the loading of the excavated material. The maximum value is reached once the material has been cut. This value corresponds to a wet soil density of 1800 kg / m^3, a bucket volume of 0.07 m^3 and a soil loosening coefficient of 0.87. The force remains constant in the time intervals corresponding to the lifting and pivoting of the arm, with the value of 1100 N. After the pivoting stops (in the 10th second of the simulation) the discharge of the material from the bucket is done in the time interval 10…13 seconds, and this force decreases linearly from its maximum value to zero.



a) b)

Fig. 5. Representation of forces acting on the hydraulic excavator bucket

Figure 6 presents the variation of the driving power for each of the actuators used in the excavation simulation process, and figure 7 shows the variation in time of the cumulated power. The diagram of the cumulative time variation of power in Figure 7 was plotted considering the absolute values of the power of the four actuators.

Analyzing this graph, it is visible that the maximum value of the power appears during the process of unloading the bucket, in the time interval 10…13 seconds, having the peak value of 13.64 kW at 11.28 seconds from the beginning of the simulation.

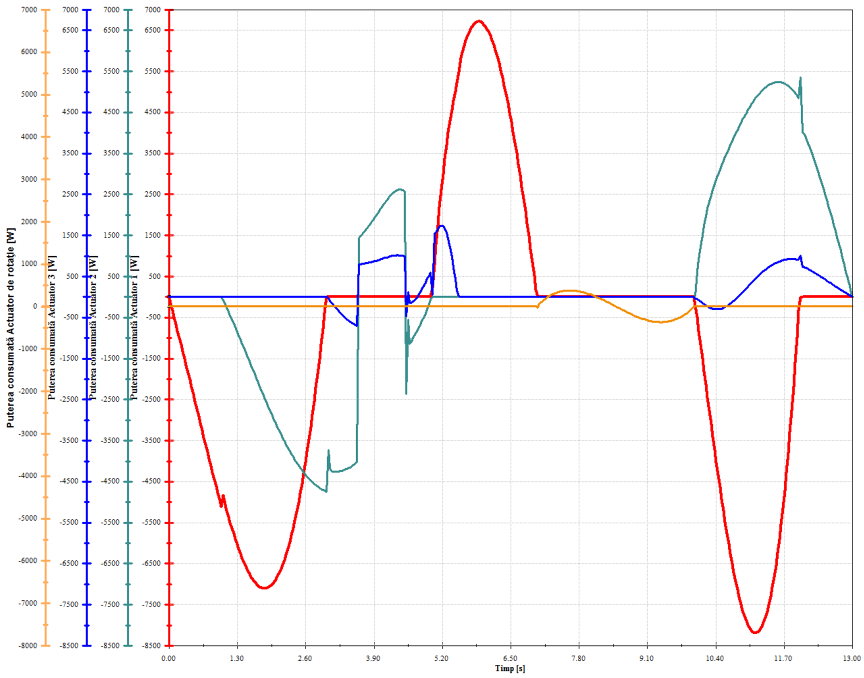


Fig.6. The variation of the driving power for each of the actuators during the simulation of the excavation process

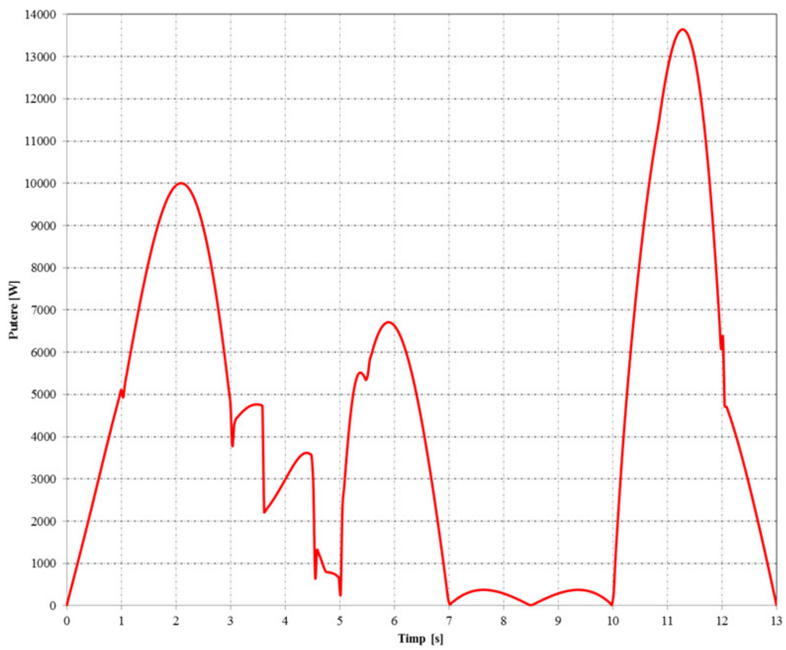


Fig.7. The variation in time of the cumulated power

If we consider the total efficiency of power transmission from the excavator motor to the actuators is 0.8, the value of the calculated maximum instantaneous power does not exceed the power of the excavator motor.

$$P_{max} < \eta \cdot P_{inst} \tag{1}$$

where:

P_{max} is the calculated maximum power;

$\eta \cdot$ is the efficiency of power transmission from the motor to the actuators;

P_{inst} is the installed power.

For the power variation graph in Figure 7, its average and effective values were calculated. Thus, the average value of power is 4.38 kW and the actual value of power is 5.83 kW.

3. STUDY OF THE STRESS ON THE EXCAVATOR BUCKET

There are several forces exerted on the excavator arm: the excavation force, the weight of the displaced material, the weights of the components as well as the forces of inertia.

After performing the analyzes using SOLIDWORKS software, the Von Mises stress variation was obtained for the entire simulation time. In Figures 8, 9, 10, 11 and 12 we present the Von Mises stresses corresponding to the most important moments during the simulation of the excavation process.

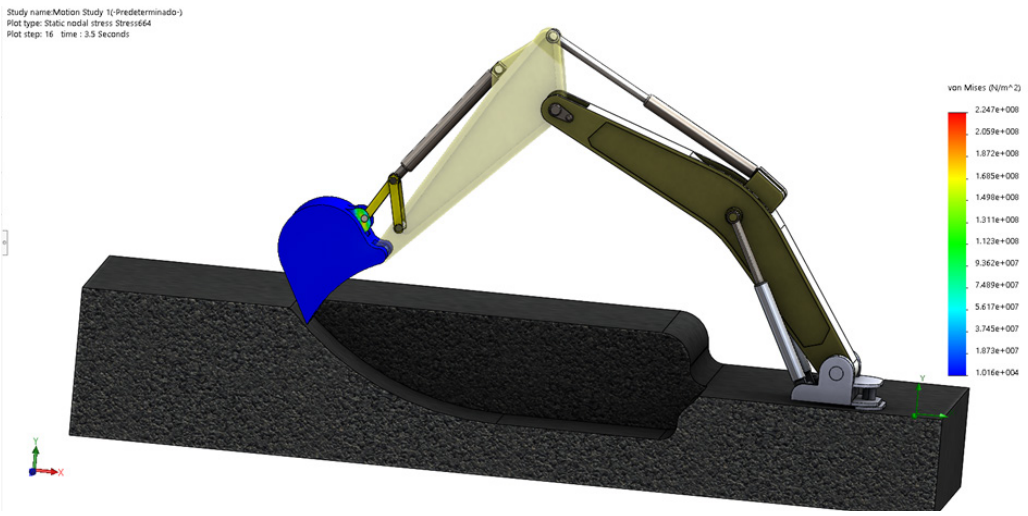


Fig. 8. Von Mises stress at the start of material cutting.

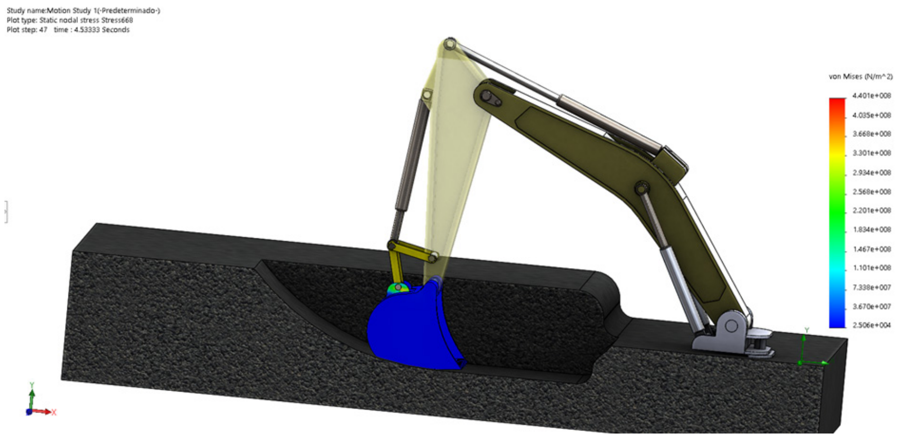


Fig. 9. Von Mises stress at the end of material cutting

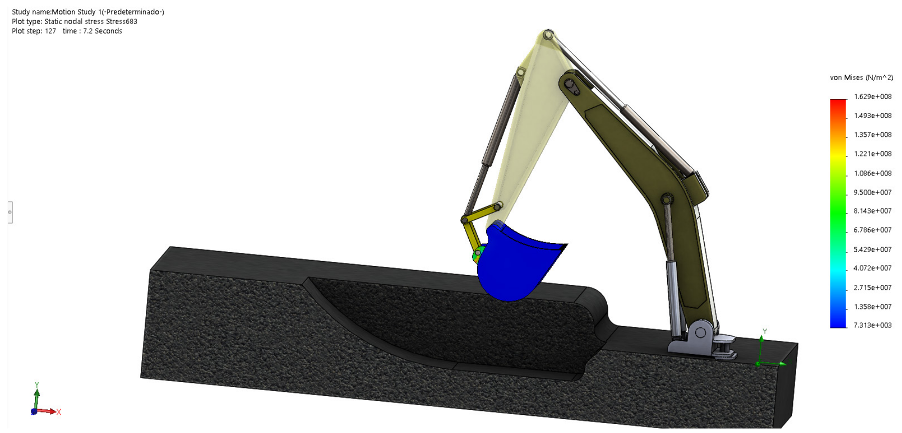


Fig. 10. Von Mises stress at the end of excavated material lifting

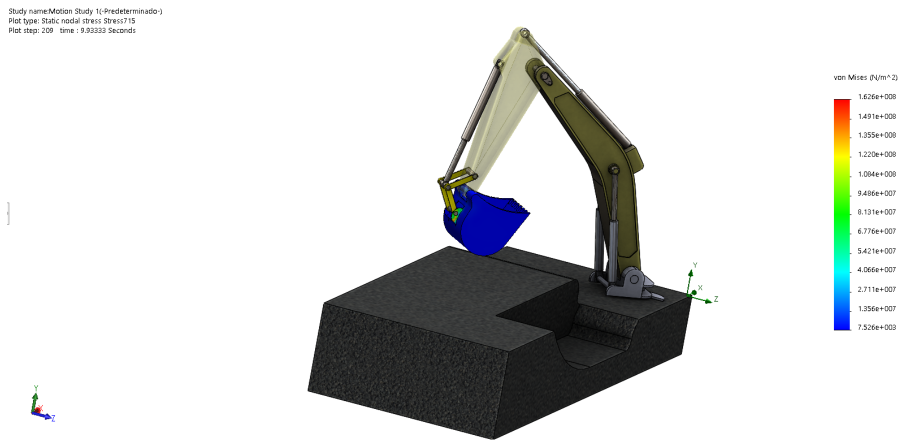


Fig. 11. Von Mises stress at the end of the excavator arm pivoting movement.

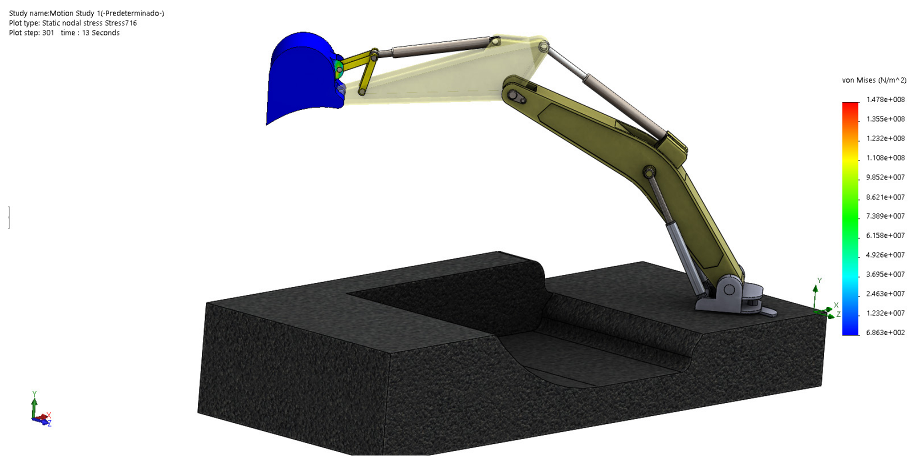


Fig. 12. Von Mises stress at the end of material discharge.

Table 1 summarizes the trend of variation of the Von Mises stress, its variation representation and the action performed in the simulation. From the analysis of the obtained results it can be concluded that the highest values of the Von Mises stress at the level of the mini-excavator bucket, appear at the end of the material cutting interval because then the two forces acting on the bucket have maximum values.

Table 1 **Von Mises stress variation summary**

Action in the simulation	Von Mises stress variation interval	Variation trend
Start of material cuttingt	$\left[1,016 \cdot 10^4 \div 2,247 \cdot 10^8\right]$	↗
End of material cutting	$\left[2,506 \cdot 10^4 \div 4,401 \cdot 10^8\right]$	↗
End of material lifting	$\left[7,313 \cdot 10^3 \div 1,629 \cdot 10^8\right]$	↙
End of arm pivoting	$\left[7,526 \cdot 10^3 \div 1,626 \cdot 10^8\right]$	↔
End of material discharge	$\left[6,863 \cdot 10^2 \div 1,478 \cdot 10^8\right]$	↙

4. CONCLUSIONS

In order to be able to study the dynamics of the actual working equipment, we used a virtual model of a mini excavator. The model was developed as a set of parts between which geometric connections of coincidence, concentricity and distance were established. The study was conducted in the SOLIDWORKS using the *Motion Analysis* study type of the *Motion Study* menu.

For a start, we imposed the variation of the technological forces specific to the studied operating regime. They refer to the cutting force considered constant, which occurs during the time of actual excavation, and the force given by the weight of the material loaded in the bucket, which has a linear increase during cutting, is constant during pivoting and decreases linearly during unloading.

The weight of the components of the assembly but also the forces of inertia were highlighted by the introduction of gravitational acceleration.

The power required for excavation in its various phases was determined by simulation, taking into account the related technological, inertial and resistance forces, corresponding to the operating regime.

The variation of the actuating power of the 3 hydraulic actuators of the arm and of the one that performs the pivoting movement as well as the cumulative diagram of the actuating power were determined and represented graphically, calculating the average and effective values.

Finally, taking into account all the forces acting on the model, we performed an analysis of the excavator bucket load by calculating the von Mises stress from the beginning of the bucket movement, until the end of unloading.

REFERENCES

[1]. **Dimirache, G., Zamfir, V.** *Ingineria sistemelor mecanice*. Editura Focus, Petroşani 2002.

[2]. **Fodor, D., Iliaş, N., Ţiştea, D.** *Mecanizarea în exploatările miniere la zi*. Editura Tehnică, Bucureşti, 1978.

[3]. **Iliaş, N.** *Maşini miniere, exemple de calcul*. Editura Tehnică Bucureşti, 1993.

[4]. **Kurowski, P.,M.** *Engineering Analysis with SOLIDWORKS® Simulation 2015*.

[5]. **Marian, I.** *Utilaje de încărcare şi transport minier*. Editura Tehnică, Bucureşti, 1991.

[6]. **Popescu, F. D., Radu, S.M., Andras, A., Brînaș, I.** *Infografică, modelare şi simulare asistată de calculator*. Editura Universitas, Petroşani, 2020.

[7]. **Popescu, F. D., Radu, S. M., Kotwica, K., Andraș, A., Brînaș, I. K., Dinescu, S.** *Vibration analysis of a bucket wheel excavator boom using Rayleigh's damping model.* New Trends in Production Engineering, 2(1), 233-241.

[8]. **Radu, S.M., Popescu, F.D., Andraş, A., Kertesz, I.** *Transport şi instalaţii miniere – varianta electronică*, Editura Universitas, Petroşani, 2018.

[9]. **Sham, T.** *SOLIDWORKS Simulation 2016: A Tutorial Approch*. CDCIM Techologies, Schereville, Indiana 46375, USA.

This page intentionally left blank