MINISTRY OF EDUCATION
UNIVERSITY OF PETROŞANI
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Domain: MINES, PETROLEUM AND GASES

# THESIS

## CONTRIBUTIONS TO THE STUDY OF MINING EXCAVATION EQUIPMENT THROUGH MODELING AND SIMULATION IN ORDER TO IMPROVE THEIR FUNCTIONAL PERFORMANCES

**- SUMMARY -**

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The exploitation of deposits of pits is achieved by continuous operation of the production line equipment comprising bucket-wheel excavators. The dump and storage equipment.

The bucket-wheel excavator is a continuous-action machine used in surface mining. It cuts the rock with the wheel-mounted buckets, at the same time executing the transport of the dislocated material by means of the belt mounted on the wheel arm and the pick-up and delivery lanes to the continuous transport means of the quarry. The working member is the wheel, which executes through the arm a rotation movement in a vertical plane under the action of the lifting cables and a pivoting movement in the horizontal plane through the rotating mechanism.

For bucket-wheel excavators the cutting process is influenced by the forces that oppose the advancement of the working and cutting bodies. Depending on these forces, it is determined the choice of operating method, the equipment used and the operating parameters of the excavators.

The value of the cutting forces can be determined by calculation or by experimental methods. Their size will impose the constructive parameters of the working bodies and their position during the operation process.

The excavation resistance of the rocks is also influenced by the position of the cutting part of the working member with respect to the layer in which the cutting is performed. In this respect, the angles between the working member and the contact surface of the excavated rock are decisive.

The analysis of the causes that determine the interruption of operation of the excavators showed that the failures of the cutting and loading system, which also includes the bearing structure of the hinged wheel, account for about 32% of the total defects of the mechanical subassemblies.

The objective primarily pursued in this PhD thesis is to create a virtual model of cutting and loading system that allows simulating the effects of the excavation. Thus, the virtual model can be used in the study of fatigue that appears especially in the bearing structure of the wheelbase. Defects affecting this structure can lead to serious events that can lead to significant economic losses as well as losses of human lives.

The system of cutting and loading is subject to the action of variable forces in time, with periodic character, produced by:

- operation of the conveyor belt mounted along the load-bearing structure;
- the actuator of the bucket-wheel;
- excavation forces, which are composed of:
    - forces corresponding to excavation resistance;

▪forces corresponding to the weight of the excavated material.

It should be noted that of the periodic forces listed, the highest values are recorded by the excavation forces.

The research method applied to achieve the stated objective has focused mainly on:

- finite element analysis of the behavior of the teeth on the wheel excavator buckets;
- determining the driving power of the bucket-wheel;
- determining the motor moment and the forces acting at the level of the axle of the bucket-wheel;
- creating a virtual model using the SOLIDWORKS application of the cutting and loading system;
- modal analysis of the virtual model of the excavator arm;
- analysis of the response in time of the model of the cutting and loading system under the action of the excavation forces;
- analysis of the frequency response of the model of the cutting and loading system under the action of the excavation forces;
- proposing research directions regarding the study of fatigue for the bearing structure of the hatch wheel and the study of its dynamic frequency response for different values of the inclination angle of the excavator arrow.

The proposed objectives determined the organization of the Doctoral Thesis in nine chapters:

CHAPTER 1 - *THEORETICAL ASPECTS CONCERNING THE DISPOSAL OF THE COAL CLEANING*. The characteristics of coal during mechanical cutting are presented in this chapter and the randomness of the cutting forces is highlighted.

CHAPTER 2 - *IMPROVEMENT OF THE FUNCTIONAL PERFORMANCES OF THE BUCKET-WHEEL EXCAVATOR TEETH USING THE FINITE ELEMENT METHOD*. Here are presented the fundamental concepts of the finite element method, the fundamental steps of performing the finite element analysis, constructing and solving the model, as well as interpreting the results. An important part of this chapter is dedicated to finite element analysis of the behavior of bucket-wheel excavator teeth. Here are presented the geometric parameters of the teeth of the bucket-wheel excavators, highlighting the influence of the location of the teeth on the cutting edge of the buckets on the geometric and resistance parameters. At the end of the chapter are presented a series of solutions for reducing teeth demands.

CHAPTER 3 - *SIMULATION AND MODELING OF THE OPERATING PARAMETERS OF THE BUCKET-WHEEL EXCAVATOR DURING THE EXCAVATION PROCESS*. At the beginning of the chapter, a series of general considerations regarding bucket-wheel excavators are presented. The excavation parameters are defined and their

calculation is presented. The definition and calculation of the cutting parameters constitutes the starting point for carrying out within this chapter a graph-numerical method for calculating the operating power of the excavator bucket-wheel. In the last part of chapter 3, a method of determining by modeling and simulating the operating power of the excavator bucket-wheel is presented using the SOLIDWORKS ® application.

CHAPTER 4 - *MODEL OF EXCAVATOR ARM ESRC 1400 30/7 FOR SIMULATING THE EXCAVATION PROCESS* . The purpose pursued in this chapter is the creation of a model of the excavator arm ESRC 1400-30 / 7. This model will be used to model and simulate excavator arrow behavior at the excavation request. For this we considered that the excavator arm is composed of three sections, which we built and assembled with the SOLIDWORKS ® application. The constructive complexity of the bucket wheel required the creation of a virtual wheel having the same mass as the actual bucket-wheel. All the equipment and machinery mounted on the excavator arm were imposed by elements specific to the SOLIDWORKS ® application . The ten cables for lifting the excavator arm were modeled by spring-type elements that have an equivalent elastic constant, equal to that of the cable system.

CHAPTER 5 - *MODAL ANALYSIS OF THE ESRC 1400 EXCAVATOR ARM MODEL* . At the beginning of chapter 5, the theoretical considerations regarding modal analysis are presented and the concepts of discrete systems and distributed systems are introduced. The latter are the basis of the method of modal analysis by superposition. The purpose of modal analysis is to determine the number of ways that must be considered in the dynamic analysis of the excavator arm for the excavation request. In this sense it is fundamental to determine the cumulative effective factors of mass participation on the three directions of the coordinate system.

CHAPTER 6 - *LINEAR DYNAMIC ANALYSIS OF THE ESRC 1400 EXCAVATOR ARM MODEL*. The chapter begins by presenting the principle of dynamic analysis of the response of the excavator arm in time. The forces simulating the excavation request both under permanent and overload conditions were determined in Chapter 3. The analysis was performed for the three directions of the coordinate system for global damping of 2%, 5% and 10% of the critical damping as well. and for variable damping depending on the modal frequencies. The graphs of variation of the acceleration and those of the deformations were determined under the action of the excavation forces. The results regarding the accelerations compared to the experimental determinations validate the simulation model of the excavator arm.

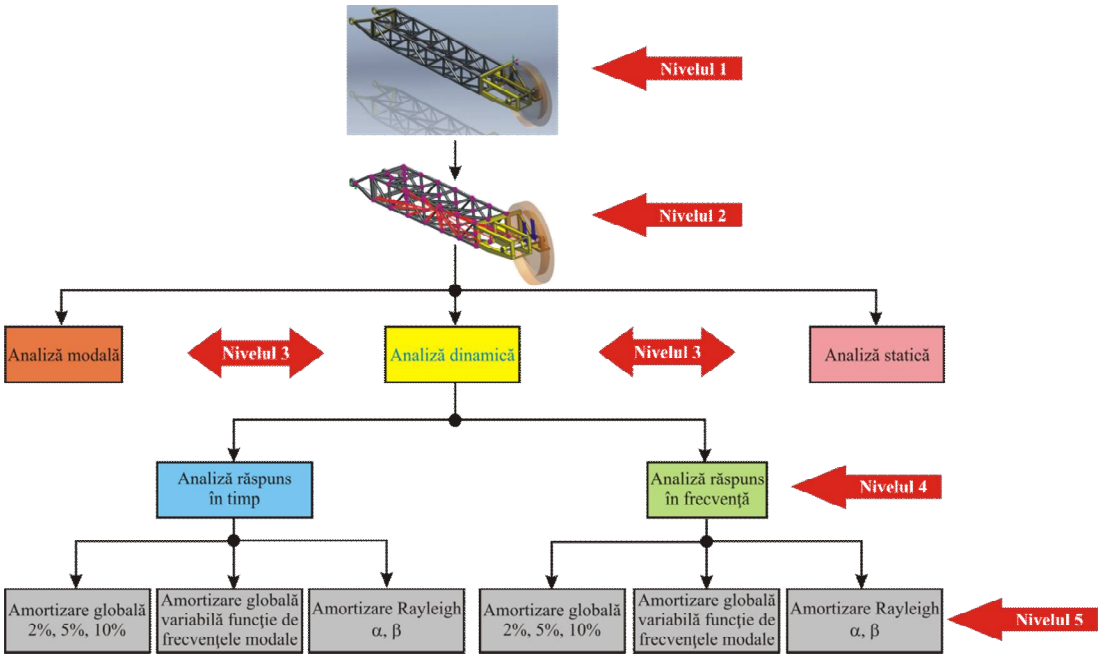
CHAPTER 7 - *LINEAR DYNAMIC ANALYSIS OF THE FREQUENCY RESPONSE OF THE ESRC 1400 EXCAVATOR ARM MODEL* . As in the previous chapter, the principle of dynamic analysis of the frequency response of the excavator arm is presented. Now we have considered the variation of the periodic force in the permanent regime over a time

interval corresponding to a period. We approximated the variation of force through a Fourier series. This allowed the plot of the variation of the force to be plotted according to frequency. The values corresponding to this graph were used in the SOLIDWORKS ® application to determine the frequency response of the excavator arm structure.

CHAPTER 8 - *DYNAMIC ANALYSIS OF THE ESRC 1400 EXCAVATOR ARM MODEL USING RAYLEIGH DAMPING*. To begin with, general considerations on Rayleigh damping are presented. For this using the results of the modal analysis we determined the values of the two damping constants, specific for viscosity and elasticity. Using the SOLIDWORKS ® application and imposing a Rayleigh type damping, we determined the dynamic response in time and frequency of the excavator arm structure for the three directions of the coordinate system. At the same time, in this chapter I have highlighted the deformations resulting on the excavator arm following the dynamic analysis of the response over time.

CHAPTER 9 - *STATIC ANALYSIS OF THE ESRC 1400 EXCAVATOR ARM MODEL* . The static analysis of the model of the excavator arm was performed taking into account the actual weight of the excavator arrow, the weight of the kinematic chain of actuation of the bucket wheel , the weight of the conveyor mounted inside the excavator arm, the weight of the virtual bucket-wheel and the actual value of the force resulting from the excavation process. Thus, we determined the deformations of the excavator arm structure, the axial and shear force diagrams as well as the moments diagram corresponding to the static load.

GENERAL CONCLUSIONS, OWN CONTRIBUTIONS AND FUTURE DIRECTIONS RESEARCH




*The objectives of the excavator arm analysis during the excavation process*

At the end of the thesis are presented proposals for future directions in research and contribution consisting of:

- finite element analysis of von Mises tension and the deformation of the teeth with which the excavators from the Oltenia Basin are equipped, taking into account the clamping condition of the teeth to the bucket-wheel;
- the design of some devices that would better coat the tail of the tooth in order to increase their reliability, by reducing von Mises tension and deforming the teeth;
- designing graph-numerical method for determining the power of bucket-wheel excavators, starting from a slice of determining the amount of excavated to a switch arm and taking into account the specific energy consumption;
- conceiving a numerical method by determining the power of the bucket-wheel excavator. This method allows to determine the graph of variation in time of the excavation force, which represents the source of vibration in the study of the dynamic regime of the excavator arrow;
- we have developed a virtual model of the excavator arm ESRC 1400. Its validation by comparing the simulation results on the response of the experimental load-bearing structure allows the use of constructive concepts used in this study arm embodiment shedder other types of excavators;
- we performed the modal, dynamic and static analysis of the virtual model analyzed according to the figure below.