Automation of design for dynamic loading at the designing stage of mining machinery

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Abstract. Meeting the growing needs of the state’s economy for the raw materials needed for the production of ferrous and non-ferrous metals accelerates the technical re-equipment of the mining industry through the introduction of new, more powerful equipment. This circumstance determines the urgency in the automation of calculations at the design stage of mining machines. The originality of the developed software product is in consideration of the actual loads acting in the working equipment of a career excavator. Actual dynamic loads significantly exceed their calculated values, which leads to an increased number of structural element failures. At the design stage, with the use of the developed program, it is possible to establish rational cross-sectional dimensions of the handle metalwork taking into account the actual loads arising during the rock mass excavation and stress concentrators.

1. Introduction

An open mining method is most developed in the global mining industry. The total volume of mining by the open method is 75-80% in the world. For muck loading in the quarries of the Russian Federation, crawler mounted mining excavators are used. Most of them were made in the 70-80s of the 20th century.

Based on the analysis of evidence, scientific publications and expert findings, it was established that the percentage of depreciation of fixed assets in the mining industry is quite high and reaches 70-90%.

Mining equipment operation in this state is associated with an increase in the cost of its maintenance, which ultimately leads to an increase in the cost of mining and processing of mining products.

Productive work of mining excavators is about 65-70% of the total working time, 30-35% of the time is downtime for various reasons, including 45-50% of the time lost as a result of various kinds of failures and accidents [1, 2].

The analysis of the mining excavator reliability shows that 40% are metal constructions of the total electromechanical equipment failure. Based on the analysis of statistical data published in the scientific and technical literature, it has been determined that the greatest number of failures is associated with loads that exceed the limiting values and arise due to the relatively low machinists’ qualification, poor readiness of the mined rock for excavation. This circumstance is usually not taken into account when designing mining excavators. As a result, there is a need to develop a software product for determining loads in the working equipment of mining excavators [1-3].
The main purpose of creating a software product is to automate the calculation process, with the possibility of taking into account when designing mining excavators, the ultimate loads that occur in the handle when digging mined rock, as well as control modes that are implemented by machinists with different length of service.

The software product should solve the following tasks:

- automation of the calculation process taking into account the actual loading conditions for the main steel structures of mining excavators;
- remaining life prediction for excavator metals, taking into account influencing factors to ensure the necessary excavator reliability.

2. Methodology

The peculiarity of mining excavator operation is that the external loads acting on the working equipment structure and the machine rotary platform change over time and are applied with a certain frequency.

In the roach development, in the process of excavating the mined rock the working equipment and drives of the machine experience both static and dynamic loads, the numerical value of which in most cases cannot be determined for given specific operating conditions. As well as the load in the vertical plane and the horizontal load from the forces of inertia when turning the machine to dump a bucket and when returning back into the face. The alternating nature of loading leads to a periodic change in stresses in the working equipment elements and metal structures of the machine, which causes the occurrence of fatigue cracks and the structure destruction, and as a result leads to emergency failures. An excavator's working equipment is in particularly difficult loading conditions during impact penetration of the bucket teeth in to the face, which is often observed during breakdown and secondary penetration into the treated rock bench.

In order to determine the dynamic loads on the elements of the excavator working equipment in the design, the classical method is used, with the reduction of the structure mass and rigidity to more simplified design schemes with two or several masses. The calculations determine the stresses in the elements of its metalwork, as well as the external loads transmitted to the elements of the CME (crawler-mounted mine excavator) metalwork, through the lifting ropes that occur during the static and dynamic locking of the bucket in the face.

This program is necessary at the design stage of mining excavators and allows to determine more accurately the estimated life of steel structures, taking into account the actual stress-strain state that occurs when digging the mined rock. In order to create a software product, Visual Basic for Applications was chosen as programming language [4, 5].

Creating a software product is achieved through the detailed study and implementation of certain stages to be performed [4, 5, 6]:

- program design stage - many usage scenarios for the certain properties set implementation of the new system;
- the stage of creating a conceptual model - an algorithm for the interaction of four program modules;
- stage of structuring program data;
- stage of the mathematical description of the program;
- software product testing stage.

The conceptual model of the software product for calculating the loads in the working equipment of mining excavators includes:

- information input module;
- module for determining loads in the working equipment of mining excavators;
• result output module;
• graphing module.

The information input module is responsible for the user entering the initial data into the program, verifies the correctness of their input. The program has the following limitations: it is impossible to enter negative numbers, depending on the mined rock, the range of the resistance coefficient of the mined rocks to digging and the coefficient of mined rock loosening varies, and also the speed of lifting the bucket from the driver’s experience changes.

The module for determining loads in the working equipment of mining excavators is responsible for the calculation according to previously known formulas. All calculations performed by the software to determine the loads in the working equipment of crawler-mounted mining excavators correspond to the known algorithms and formulas.

The output result module displays the final and intermediate results.

The graphing module visualizes the dependence of the maximum calculated effort in the ropes on the bucket lifting speed.

3. Implementation

Entering the data into the program. In order to ensure the ease of software use for determining loads in the working equipment of mining excavators, a user form has been developed. Based on the compiled mental map of the initial data, the necessary information and data for the calculation were grouped relative to their categories (figure 1).

![Figure 1. The mental map of the source program data.](image)

In order to determine the working equipment loads of mining excavators, the program interface is divided into three areas: the choice area of the excavator model, the choice area of the excavator characteristic properties, the area of functions. A distinctive feature of data entry is that some parameters are coloured grey when choosing an excavator model. This means that the parameters are set by default and cannot be changed, but if necessary, the user can click the «circle» next to the window and correct the parameter, but only in the allowed range, otherwise the program will display a message about incorrect input.

On the «Bucket» tab, the user selects or adjusts such parameters as: bucket capacity, proportionality coefficient, bucket weight coefficient, bucket lifting speed, rotation angle when unloading, maximum unloading radius, maximum digging radius, bucket unloading time. The user has
the right to change such values as the rotation angle during unloading, the bucket unloading time, the horizon boom angle. The program has limitations: you must enter positive numbers (figure 2).

The «Boom» tab contains such parameters as: boom length, boom foot radius, luff to the horizon, boom foot pin height.

On the «Mined Rock» tab, the user selects the category of the excavated rock. Elective characteristics are the rock density, the resistance coefficient of the rock to digging, the coefficient of the rock loosening. Depending on the mined rock, the range of the rock resistance coefficient to digging and the loosening coefficient of rocks change.

The «Handle» tab contains such parameters as the handle length and the weight coefficient of the handle. This tab is not subject to change, but is displayed so that the user knows which values are involved in the calculations.

The «Other» tab displays the parameters of the single-bucket excavator mass, the platform rotation speed and the exponent.

After entering and adjusting all the parameters presented on the form, the user can proceed to the automatic calculation of the loads in the working equipment of mine excavators. In order to do this, it is necessary to go to the function area.

The work order of the program. It is necessary to choose a model of a crawler-mounted mining excavator, for which calculations will be made. Excavator models are offered from a database that the administrator can adjust. After that, the software automatically offers options for bucket, handle, boom. As a rule, these parameters for each model of the excavator are unchanged, but if desired, the user can adjust them. After checking all the data, selecting the rock type to be excavated, the user must press the button on the «Calculate» form. The program checks the correctness of user input, if there are any errors, they are displayed as a message. Otherwise, the calculation is made according to predefined formulas, and displayed on a new Excel sheet, the sheet name is determined by the excavator model [7-10].

When you click the «Diagram» button, the results of calculations are used to plot the bucket lifting speed as a function of the efforts that occur in the ropes during excavation of the mined rock mass.

The «Clear Total» button is responsible for clearing the Excel sheet on which the last calculations were made. The «Exit» button, respectively, exits the program launched by the user, retaining the previous calculations, if there are some.
4. Conclusions
The developed computer program, based on a modern numerical method of calculation, will allow solving problems in the design of quarry excavators, taking into account the actual loads due to the specifics of their operation.

References
[1] Velikanov V S and Gurov M Yu 2018 Magnitogorsk Publishing House of Nosov Magnitogorsk State Technical University 217
[2] Nasonov M Yu 2009 Assessment of the durability of bearing metal structures of single-bucket excavators in the development of blasted rocks 325
[3] Saitov V I, Andreeva L I and Krasnikova T I 2012 Modern problems of science and education 2
[4] Pechnikov A N and Shikov A N 2014 Design and application of computer technology training 393
[5] Vendrov A M 2010 Finance and Statistics 455
[6] Artyomov M A and Karaichev S A 2007 Development and standardization of software and information technology. Development and execution of software documentation 41
[7] Velikanov V S 2013 Bulletin of KuzGTU 4 43
[8] Hakim H, Sellami A and Ben-Abdallah H 2017 Identifying and localizing the inter-consistency errors among UML use cases and activity diagrams: An approach based on functional and structural size measurements 15th IEEE/ACIS International Conference on Software Engineering Research, Management and Applications 289
[9] Goma H 2014 UML. Designing real-time systems, parallel and distributed applications. trans. with English (Moscow) p 704
[10] Khakhar D and Nayak A 2018 Capturing Performance Requirements of Real-Time Systems Using UML/MARTE Profile Advances in Intelligent Systems and Computing 703