Reliability of Mining Machines and Development of the Express – Diagnostic System: State and Prospects

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Abstract

This article summarizes some of the results of our work in terms of considering various issues of reliability of mining machines – mining excavators. In this case, we are talking about the development of the basis, structure and elements of a system for express diagnostics (analysis) of these machines under operating conditions, which should be adjusted for the conditions and capabilities of engineers operating these machines to maintain their state within the framework of homeostasis (in the future, and control their state). In addition, the article presents a scheme that allows describing in an enlarged manner the entire life cycle of a mining machine, taking into account both design and operation. Additionally, there is a list of tasks that the authors plan to solve in the future.

Keywords: Mining machines, quarry excavators, express diagnostics system, reliability, homeostasis.

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1 Introduction

Within the framework of building inclusive capitalism and, in the future, the sixth technological order, the volume and availability of minerals are playing an increasingly important role, which, until the current energy of hydrocarbons and the core is completely replaced by green energy, should ensure the sustainability of civilization at the proper level, gradually entering the framework of the so-called carbon agenda.

In other words, mining currently and for the future until 2030 should be intensified with maximization, expansion of environmental and social frameworks, norms and regulations. To do this, it is necessary to continue improving the machines and mechanisms used for the extraction and processing of minerals.

Within the framework of this work, it is not possible to consider the entire range of machines and mechanisms used in the extraction of minerals. It is also impossible to consider all types of mining. It is necessary to narrow the subject field of this work.

In other words, now we will focus only on open-pit mining and we will talk only about quarry excavators.

At the same time, we will talk only about their reliability – about what the "mechanism" should be, which needs to concentrate both approaches to its numerical evaluation, and methods of maintaining it in operating conditions and methods of increasing it during design. The purpose of this work will be to briefly illustrate what we have already done in this direction and outline ways to move forward.

2 Method

A thorough analysis of the conditions and features of the operation of quarry excavators with different types of drive in the conditions of the entire former Soviet Union over the past 70 years, coupled with a detailed literary study of the works of all our main predecessors (here, for example, we will point to some fundamental methodological works that had a significant impact on us [1–7]), supported by a number of our original theoretical works [8–10 and many others], allowed us to obtain a scheme (see Figure 1), which combines, in fact, the entire life cycle of the machine, local design procedures and experiments (virtual and full-scale), and the basic procedures and processes of operation and diagnostics.

Naturally, each element of the above scheme can be detailed with the accuracy and depth required by the researcher (figure).

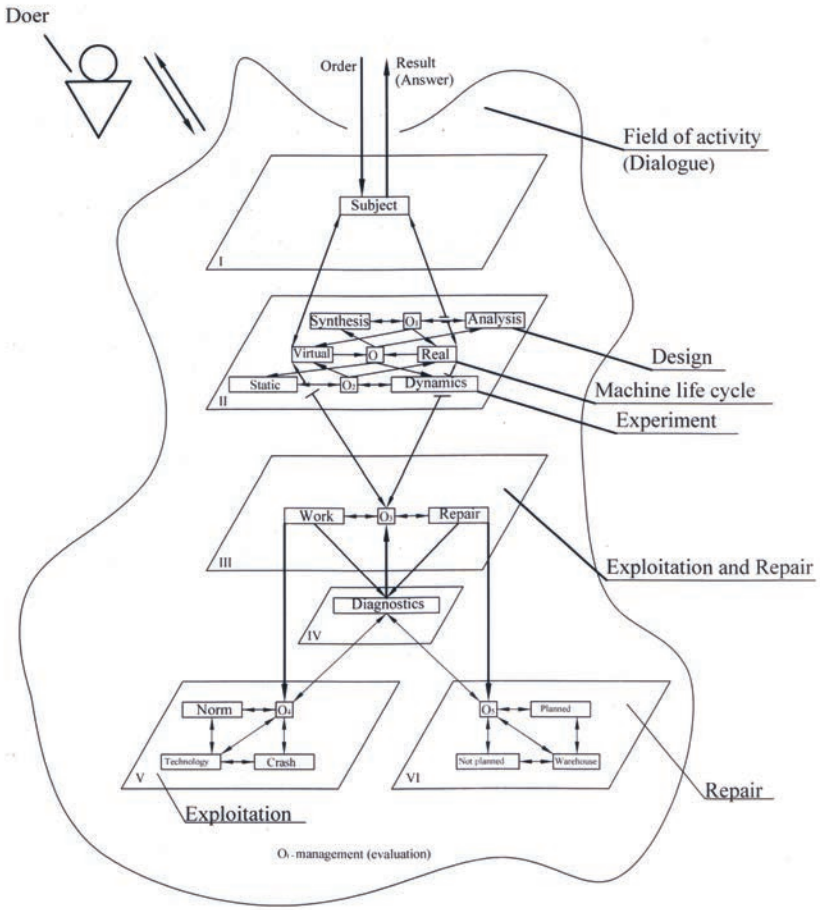

Figure 1 Excavator life-cycle (Foundation for the creation of the science of machines for earthworks).

Note that the scheme is methodologically induced by the works of the Moscow methodological circle under the leadership of G.P. Shchedrovitsky [2, 5, 6, etc.], some considerations of the Russian philosopher M.M. Bakhtin regarding the idea of polyphony (a few words about this are said in our article [11, etc.]), and besides the idea of homeostasis [4, etc.] and a number of biological analogies we have identified between the working equipment of excavators and the human body [12, etc.].

Note that the story in detail about the scheme in Figure 1 will be presented later in our other works.

Recall that the solution of the entire range of issues of reliability of mining machines today is expedient and possible only with the use of all modern achievements of information technology. Therefore, we proposed to develop a system of express diagnostics of these machines, which should be used during their operation by the engineers operating these machines. The specified system should contain not only methods and approaches to the diagnosis of mining machines, but also models for operational engineering analysis and satisfactory solutions to a significant range of typical theoretical problems that an engineer may encounter in practice (taking into account their training and the equipment they have). In our opinion, using such a system, engineers operating mining machines for the first time will have the opportunity to monitor the reliability of these machines in real time – to monitor and manage their current state – to maintain these machines in a state of homeostasis. In other words, a significant practical step will be taken towards the so-called "intellectual career".

At the same time, the scheme we have developed (see Figure 1) can be successfully laid both in the foundation of the development of the specified system of express diagnostics of mining machines [13, 14, etc.], and in the basis of the study of all issues of reliability of mining machines at all stages of their life cycle, and eventually become a reference scheme (foundation) in the design of the science of machines for excavation.

Consideration of the above scheme allows us to note that the issue of reliability is inherent in almost every stage – at the same time, reliability at these stages should and can be interpreted, evaluated and determined in different ways.

So it is quite obvious that the issues of mathematical and physical structural reliability are of considerable interest in the formation of the terms of reference and at the early stages of the design of quarry excavators, having a direct and significant impact on the quality of the machine design, while in operation a much more important role is played by the optimal structure of machine operation services at a particular quarry or facility of operation, and optimal timing and quality of the impact of this service on the fleet of machines.

However, as part of the creation, application and improvement of our scheme (methodology), we have the opportunity to build a continuous chain of assessing the reliability of a quarry excavator throughout its entire life cycle. For this colossal amount of work, it is necessary to outline the trajectory of our thought – and indicate what we have already done.

3 The Trajectory of the Study of the Reliability of Quarry Excavators

At the moment, within the framework of the fundamental foundations of the express diagnostics system of quarry mining machines being developed by us, the following works have been performed (constituting, to one extent or another, its foundation, structure and being its elements):

- analyzed failures mining excavators in the USSR and in Russia [15 and others]. At the same time revealed a significant benefit from the methods of harmonic analysis that will make it possible to build models for prediction of failures, which in turn can be extended with the active use of correlation and regression analysis, etc.;
- identified the so-called "weak" places of load-bearing structures and working bodies of a number of bucket wheel excavators, and dragline excavators [16, 17, etc.];
- by generalizing the works of a number of authors, we have proposed a classification of defects in bearing metal structures of dragline excavators;
- improved practical approach to obtaining experimental data on real welds of the machines in question;
- an engineering approach to the assessment of the theoretical stress concentration coefficient (TCC) in various welds of excavator dragline booms is proposed [14, etc.];
- the task of applying a scenario approach (graph theory) to the assessment of the state of excavator dragline booms is set;
- the existing methods of non-destructive testing have been analyzed and an integrated approach has been chosen for the superstructures and boom of dragline excavators with the acoustic-emission approach dominating. Our colleagues conducted full-scale tests of this method [18, 19, etc.]), which showed its effectiveness;
- some ideas regarding the reorganization of information chains in management systems at mining enterprises are planned for development;
- a link of TCC studies with an assessment of the metal condition of the bearing metal structures of dragline excavators was carried out;
- the analysis of the problem of soil sticking to the elements of mining machines was carried out [20, etc.];
- the problem of wear of working bodies and working equipment of quarry excavators is analyzed [21, etc.];

- an approach to assessing the wear rate of bucket teeth of rotary excavators is developed [22, etc.];
- the structure of a software package for express diagnostics of the current characteristics of bearing metal structures of dragline excavators in terms of assessing their fatigue state is outlined;
- several physical models describing the dynamics of quarry excavators with different types of drive have been built [10, etc.].

In addition, the framework of the express diagnostics system includes previously performed work on: assessing the energy consumption of excavators of the ECG type [13]; calculating the specific pressures of the tracks on the ground for excavators with hydraulic drive; determining the maximum static loads of hydraulic excavators when their bucket is locked in an absolutely rigid and insurmountable obstacle, etc.

We emphasize that the choice of such elements of the frame of the express diagnostics system is connected both with our subjective understanding of the problems of operating excavators, and with our objective financial and technical capabilities. In addition, the whole presented chain of issues we have considered is permeated with internal logic, when the next task follows from the previous ones and has, in our opinion, the potential for development.

Recall that all these works are more or less related to the problem of reliability of mining machines – quarry excavators. It is so obvious that the condition of the arrows of dragline excavators deteriorates during operation – fatigue failures appear – and it is fundamentally important to have an engineering approach that allows at the site of operation and by local engineering services to assess the process of degradation of materials and the structure itself.

On the other hand, in Russian engineering practice from time immemorial, little attention has been paid to the issues of physical and mathematical assessment of reliability. In other words, and taking into account all that has already been said above, this is how we see the trajectory of our further work in terms of improving the reliability of mining machines – quarry excavators (and again in large strokes):

- improving approaches to full-scale and bench experiments in terms of analyzing the working processes of quarry excavators. Development of classification of experiments, selection of standard experiments, creation of a single form of their design, conduct and description, etc.:
- creation of an approach to the analysis and management of biomechanics of the operator of a quarry excavator [23, etc.];

- synthesis of a physical model for assessing vibration effects on the operator of a quarry excavator for use in operating conditions by local forces;
- development of a methodology for calculating the main parameters of the reliability of quarry machines in their operation and design, taking into account the processes of fatigue and degradation of materials;
- further investigation of the reliability of welded joints of bearing metal structures of quarry excavators;
- investigation of the possibility of using composite materials in structures and elements of quarry excavators;
- global intensification of theoretical and experimental work in terms of improving the pivoting mechanisms, taking into account the dynamics of the working process, the base and the soil under it for dragline excavators (including accounting for gaps);
- intensification of work in terms of improving frame structures under the pivoting devices of full-turn quarry excavators with mechanical drive, with the main concentration on the conical lower frames;
- consideration of the possibility and feasibility of using a single axial piston pump in the drive of hydraulic excavators;
- creation of a new methodology for the feasibility study and evaluation of innovations in mining engineering;
- continuation of work in terms of numerical evaluation and practical minimization of the impact of wear and soil sticking on the main elements of quarry excavators. Further development of the problem of wear control (taking into account the influence of the dynamics of the machine), etc.

4 Conclusions

In this paper, having justified the expediency of further work to improve the parameters and designs of mining machines, we have provided a list of the works we have already performed, and also indicated a list of the main planned ones. At the same time, all these works follow from the methodological scheme developed by us describing the life cycle of a quarry excavator (typical of both a mining machine and a mechatronic manipulation system), which allows us to build a system of express diagnostics of mining machines, which, in turn, makes it possible to successfully consider the entire range of issues of reliability of these machines and assess their condition in real time, thereby maintaining and managing their homeostasis.

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Biographies

P. A. Pobegailo – an engineer (2000), candidate of technical sciences (2008); Received higher education at the "Moscow State Construction University" (MGSU) (1995–2000) in the field of creation and operation of construction, road and lifting and transport machines; completed two postgraduate studies – at Moscow State University of Civil Engineering (2000–2003) with a degree in Construction and Road Machinery, and at the Ural State Mining University (2006–2008) with a degree in Mining Machines and Complexes; additional education was obtained in the field of computer technology at the "Moscow State University" (2004–2006). He worked in various positions in various commercial organizations, for example, in OJSC "Moskovsky Podshipnik" (in the field of creation and implementation of automation tools for design activities) (2003–2006); from 2011 to 2021 he was a doctoral student and held the position of a senior researcher at the A.A. Blagonravov Institute of Mechanical Engineering of the Russian Academy of Sciences, doing various research on mining machines there. Since mid-2021, he has been an Independent Researcher.

Irina Gadolina was born in Moscow in 1954. In 1977 she has been graduated from Moscow Technical University with a major of Mechanic – Investigator.

Since when Gadolina has been working for Mechanical Research Institute of Russian Academy of Science (IMASH RAS) and deal mostly with reliability under fatigue impact. Random loading and Machine learning are also in scope of her interests. Gadolina got her PhD in 1990. She published more than 120 papers and chapters in the scientific books. In the nearest future Gadolina plan to perform thoroughly planned fatigue experiment for considering impact of the mutual important factors employing the experimental design methodology.