On the issue of improving the reliability of machines for open-pit mining operations with expiring or expired standard exploitation period

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Abstract. The present paper presents our new results related to the research aimed at improving reliability and safety, and reducing operating costs of open-pit mining machines. The main attention was paid by us to the failures of mining equipment. Our main focus has been on machines with the expiring or already expired standard exploitation period, which, however, are not utilized, but continue their work. The failures of mining machines have been collected by us at a number of enterprises in Russia over the past few years. After that, we analyzed and processed them. During the analysis, these initial data were presented by us in the form of frequency graphs. Further, these discrete graphs were “transferred” by us into continuous by means of harmonic analysis methods - using the Fourier series and mathematical package MATLAB. According to the results of the work, it was found out that the number of failures is growing. This can be explained by the rhythm of the nature of the occurrence of failures and connection between the failures and the physiological state of the people working and operating these machines, which was previously not given due attention.

1. Introduction
Mining machines for open-pit mining play an increasing role in the life of mankind, since their effective work provides the planet with the necessary raw materials for survival. The importance of the social and economic role of these machines, the growing demand for them, dictate more and more stringent requirements for their reliability. The reliability of mining machines depends significantly on the quality of work of engineering departments of their operating organizations. The quality of the work of these engineering services can be assessed through the concept of failure. The minimization of their number, the reduction of time and financial resources for their elimination are the main requirements for the work of engineers-operators. At the same time, we cannot affirm that the problem of failures in our country has been completely solved, because of this fact there are known problems with the reliability of mining machines. Some attempts to improve the situation with failures are presented in the present text.

At the same time, we should note that the main emphasis was made on the analysis of failures of mining machines with the expired or expiring normative exploitation period, which is due to the fact...
that there are a lot of such machines in the park of domestic equipment now. And this problem is new, because in the Soviet times this fact didn’t take place.

2. Degree of development of the topic

Serious research on the reliability of mining machines started from the late 50s - early 60s of the last century. At the time the corresponding fundamental works appeared. The number of studies increased until the end of the 90s of the last century and had the widest area of application in all areas of the national economy.

The following engineers and scientists were engaged in research on the reliability of mining machines (and various excavators): Belenkii D.M., Volkov D.P. [1], Getopanov V.N., Demin A.A., Doronin S.V., Kovalchuk V.A., Kravchenko V.M. [2], Krasnikov IU.D. [3], Krylov E.S., Kokh P.I., Makhno D.E., Morozov V.I., Moskvichev V.V., Novikov B.A., Olenev V.A., Pereponov V.I., Petrov I.V., Rakhutin G.S. [4], Reish A.K. [5], Rovkakh S.E., Semenchun P.V., Solod S.V.[6], Trop A.E., Fedorov D.I. [7], KHazov B.F. [8 9], SHenderov A.I. [10] and many others.

In addition, it should be noted that many studies and aspects of the reliability problem have been reflected in numerous regulatory and calculation documents, most of which are still relevant today.

However, despite the very significant number of publications and the huge physical and financial efforts to improve the reliability of Soviet and Russian mining machines, this task cannot be said to have been realized. Rather, on the contrary, in recent decades the problem has only grown and appears more and more new faces and colors. And, yes, our mining machines are also inferior in this part to their foreign competitors.

Therefore, any work that brings positive to this area is relevant and in demand.

3. Results

At the beginning of the work in the presented article, its authors collected statistical data on failures on several large (and in something typical) domestic quarries. It should be taken for consideration the data have been collected over a long period of several years. In addition, the authors managed to find some data on failures from these quarries during the Soviet times.

After that, the obtained data were subjected to mathematical processing using the MATLAB package (having created the required program text).

Before using the specified software, we analyzed the distribution of failures according to the time of their occurrence per day, and also studied the question of what time it takes to eliminate certain failures (all this was carried out for the annual interval). In other words, we prepared the initial data for analysis, presenting them in the form we needed, as shown in figure 1. It shows one of the frequency diagrams we received on the distribution of failures by daytime - for the night shift on one of the quarries.

During this phase of the work, we have found that in some cases there is a tendency to increase the number of accidents, decrease productivity and increase costs. Moreover, this is especially evident in the analysis of the condition of bearing metal structures of quarry excavators with the expiring or already expired standard exploitation period.

The essence of the stage of processing this data in the above mathematical package, is to go from discreetness to continuity in our studies, replacing graphs like those shown in figure 1 with graphs like those shown in figures 2 and 3 below. The course of our actions is as follows (as an example based on the frequency graph in figure 1).
Figure 1. Frequency diagram for night shift a.

Note: the digit “1” along the abscissa axis is the time interval from 7 to 8 p.m., the digit “2” is the time interval from 8 to 9 p.m., etc. Along the ordinate axis, the number of failures per hour interval (twelve-hour shifts) is marked.

Figure 2. The sum \( N \) of the terms of the series at \( N = 10 \).

Figure 3. The sum \( N \) of the terms of the series at \( N = 20 \).
First, we build a frequency polygon \( f(x) \) that is a broken line connecting the upper bounds of the rectangles that form the frequency diagram.

Next, we process the obtained piecemeal-smooth function \( f(x) \) and, using the tools of the MATLAB, we get its representation in the form of the sum of harmonics:

\[
\begin{align*}
  f(x) &= \frac{1}{2} \cdot 65,4583 + \left( 1,0362 \cdot 10^{-15} \cdot \cos\left( \frac{\pi x}{12} \right) + 3,227 \cdot 10^{-14} \cdot \sin\left( \frac{\pi x}{12} \right) \right) + \\
  &+ \left( 2,7234 \cdot \cos\left( \frac{2\pi x}{12} \right) + 4,5343 \cdot \sin\left( \frac{2\pi x}{12} \right) \right) + \\
  &+ \left( -2,8126 \cdot 10^{-15} \cdot \cos\left( \frac{3\pi x}{12} \right) + 5,3291 \cdot 10^{-15} \cdot \sin\left( \frac{3\pi x}{12} \right) \right) + \ldots
\end{align*}
\]

After that, we receive the graphs of the sums of the first 10 and 20 terms of the obtained series (they are shown in figure 2 and figure 3). Let us note that the number of harmonics is now taken by us as an example and it is not a dogma, in other cases there may be a different number of them.

In the regarded example, for the situation with twenty harmonics, the relative error is 0.3% and it seems quite satisfactory for the considered class of problems (the formula for calculating the error is not given now).

When processing the initial data collected by us in the quarries, we have built not only graphs of the type shown in figure 1, but also several more - one of them is a graph of the frequency distribution of the time required to eliminate a single failure (figure 4). These graphs are also subjected to the analysis described above using the approach we have developed.

The result of processing this graph as described above is shown in figure 5.

It should be noted that the processing of the data presented in figure 4 gives the following representation in the form of a sum of harmonics:

Figure 4. Frequency distribution of time for elimination of single failure\(^a\).

\(^a\) Note: the digit “1” along the abscissa axis is the time interval from 0 to 1 hour for elimination of a failure, the digit “2” is the time interval from 1 to 2 hours for elimination of a failure, etc. (the right interval indicates all failures with the time of elimination more than a day) The number of failures per hour interval is marked along the ordinate axis.
Figure 5. Time of elimination of single failure after processing with harmonic number equal to 30.

\[ f(x) = 12,9863 \cdot \sin \left( \frac{\pi x}{25} \right) + 11,7317 \cdot \sin \left( \frac{2\pi x}{25} \right) + 12,5488 \cdot \sin \left( \frac{3\pi x}{25} \right) + \\
+ 7,1679 \cdot \sin \left( \frac{4\pi x}{25} \right) + \\
+ 8,2908 \cdot \sin \left( \frac{5\pi x}{25} \right) + 3,9859 \cdot \sin \left( \frac{6\pi x}{25} \right) + 6,2015 \cdot \sin \left( \frac{7\pi x}{25} \right) + 0,9607 \cdot \sin \left( \frac{8\pi x}{25} \right) + \ldots \]

(2)

In this case, for the situation with thirty harmonics, the relative error is 0.3%.

4. Conclusion

In this work, for the first time in our country, the authors formulated the most important and still little-solved problem of reducing the number of failures during the operation of mining machines in open mining work that have the expiring or expired standard exploitation period (and thereby reducing costs and ensuring productivity required in the mines).

At the same time, on the basis of the significant collected amount of initial information, the important applied results were obtained (not given in the text).

The major theoretical results of this work are:

- an increase in the number of failures of mining machines in some domestic quarries located either in front of Rubikon or already after it in terms of their normative standard exploitation period was revealed;
- on one of the quarries the rhythmic nature of failure occurrence is revealed that is qualitatively the same for day and night shifts. At night, the number of failures is greater (seasonal rhythms are qualitatively the same as in the Soviet times). It provides for the necessity for further research into the impact of human biological features on the operation of mining machines;
- frequency graphs can be successfully processed by means of harmonic analysis.

At the end of this text, we note that the introduction into the practice of operating mining machines of the approach proposed by the authors of this article to the analysis of failures will increase the reliability of mining machines, reduce their accident rate and financial costs for their repair.

We also note that this study is included both in the system of express diagnostics of quarry excavators created by its authors and closely concerns the methodology for designing hydraulic-driven quarry excavators that we are developing.


References

[1] Volkov D P, Nikolaev S N and Marchenko I A 1972 Reliability of rotary trench excavators (Moscow: Mashinostroenie) p 207
[2] Kravchenko V M and Rusikhin V I 2002 Repair technology of mechanical shovels (Moscow: MGGU Publishing House) p 231
[3] Krasnikov IU D, Solod S V and Khazanov KH I 1989 Improving the reliability of mining dredging machines (Moscow: Nedra) p 215
[4] Rakhutin G S 1970 Probabilistic methods for calculating reliability, prevention and reserve of mining machines (Moscow: Nauka) p 203
[5] Reish A K 1986 Increasing the wear resistance of construction and road machines (Moscow: Mashinostroenie) p 184
[6] Solod S V 2003 Reliability of mining dredging machines (Moscow: OOO "Nedra-Biznestsentr") p 291
[7] Fedorov D I and Bondarovich B A 1981 Reliability of working equipment of earth-moving machines (Moscow: Mashinostroenie) p 280
[8] KHazov B F 1979 Reliability of construction and road machines (Moscow: Mashinostroenie) p 192
[9] KHazov B F and Didusev B A 1986 Handbook on machine reliability calculation at the design stage (Moscow: Mashinostroenie) p 224
[10] SHenderov A I, Emelianov O A and Odin I M 1976 Reliability of mining transport equipment (Moscow: Nedra) p 247