Effects of working conditions on excavator performance - longevity of metal structures

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1. Abstract
This paper presents factors exerting significant influence not only on the productivity and performance of excavators but also on the formation of cracks in the metal structures of excavators. Based on the obtained experimental results and observations of excavators working under specific conditions and subsequent analysis, it was noted that these factors determine the durability (the number of loading cycles) of excavators.

A relation between the working conditions of the spider and mine excavators in the faces and the durability of their metal structures and productivity was established. Mining technical conditions, technology of drilling and blasting operations, oversize yield and coarseness of grading of the rock have a significant impact on the reliability and performance of excavators.

The derived graphical dependencies clearly show the influence of these various factors.

2. Introduction
The main focus of the current mining industry is aimed at controlling excavator performance when investigating mining machines including excavators. Most mining literature optimizes and presents the general factors (such as the relation of the rock particle size composition and machines) influencing excavator performance [1-4].

The main focus is on the control of the level of extraction and its productivity, which is achieved by measuring the time of dump truck loading cycle, performed by the excavator’s dipper [5-6].

To increase productivity, much attention should be placed to optimize the correspondence of the excavators and dump trucks [7].

The factors influencing the residual life of the machines both in the mining industry and in other industries (not related to mineral resources extraction) are also studied, during which the main focus is on the predictions of the durability of the machines with cracks and fractures [8-9], prediction of strain cycle fatigue [10], fracture increase prediction [11-14] and evaluation of the residual life of the machines [15-16]. In the Russian mining industry, a huge attention is paid to these problems as well.

3. The excavator’s productivity
In recent literatures, the factors affecting the productivity of excavators working on the Kuzbass quarries under various operating conditions were fully investigated [17, 18]. These factors include the particle size composition, the developed rocks, the degree of the rock fragmentation, the percentage of the oversized material output and its largest size, the work quality of the ledge bottom, the height of the face, and so on. Among these factors, the percentage of the output of the oversize and particle size

distribution has the greatest influence on the excavator's performance, determined by the average diameter of a piece in the collapse (d_{av}).

Despite a significant amount of information on the performance of excavators [19, 20, 21], in particular, excavators of ESH 10/70, ESH 15/90 and ECG-12.5, EKG-20 types, the problem of establishing a connection between crack formation in the metal structures of excavators and their working conditions in the face still exists. Therefore, additional studies on the technical and operational performances are required. In this research paper, ECG-15 (18) and ESH 13/50 excavators were monitored. Time-keeping observations of their work were carried out and the factors influencing their productivity were determined.

By incorporating the idea that in the conditions of Kuzbass with existing drilling technology and blasting operations, the degree of rock fragmentation varies insignificantly within the limits of 1.3 -1.4 (with an average of 1.35) [22]. The main influence on productivity is rendered by the average diameter of a piece of rock in the collapse [22], the magnitude of which depends on the duration of the cycle of excavation.

The duration of the excavation cycle consists of the digging time, swinging to the place of unloading, actually unloading and swinging into the face. In the development of blasted rocks, its duration mainly depends on the digging time [22]. Moreover, changes in the loading of the excavator are significantly influenced by digging, while a change in the remaining parameters of the cycle affects the loading to a much lesser extent. With a stable degree of rock fragmentation, the duration of digging and the quality of the face preparation are directly related, which is determined by the particle size composition of the rocks.

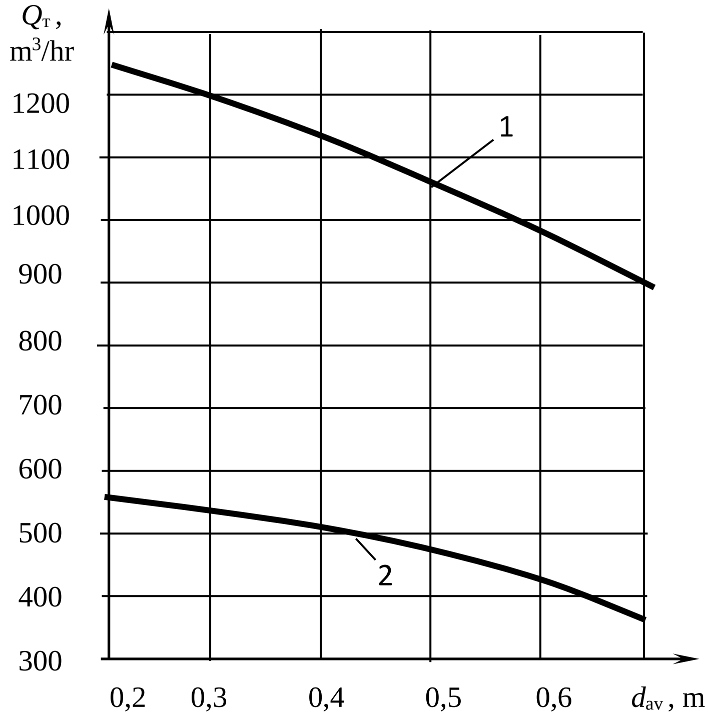

Figure 1. Technical performance against rock particle size composition: 1 – EKG-15(18); 2 – ESH 13/50.

In order to determine the parameters of the cycle, chronometric observations were made during the work of excavators in the face with different particle size composition (d_{av} = 0.2 - 0.7 m). Based on the results of these observations, variation in digging time for fixed levels of particle size composition was established and its mean sample values were determined. Based on this analysis, the relationships between the particle size composition and digging time of the excavators and the presence of a close correlation dependence between these parameters (the correlation ratio was (0.7 -

0.82) were established. It was established that the digging time significantly depends on the particle size composition of the excavated rock mass and consequently and has a prevailing influence on the excavator's productivity. The obtained data were used to calculate the technical performance of excavators (as shown in Figure 1).

4. Longevity of metal structures of excavators

In the course of this research, it was found that in the metal structures of excavators, cracks are formed during operations with great intensity; these are mainly on the surface and through cracks in booms, sticks, superstructures, supporting frames and swivel plates. The durability of metal structures with crack-like defects was established taking into account the sizes of existing cracks, the number of load cycles during the subsequent operation, their frequency and amplitude. Information on loading parameters and stress-strain state in the most dangerous zones of metal structures (flange joints of spider (walking) excavator's boom and reinforcement of truck frame in open-pit excavators) was obtained by direct measurements of deformations using special equipment. The number of loading cycles, their frequency and amplitude were established during the processing of obtained oscillograms.

To assess the stress state of the metal structures of excavators, deformations in crack formation zones were measured. Resistance sensors (tensoresistor) were glued to dangerous points of the structures, the amplifier was connected to a loop oscillograph through the output. The interpretation of the obtained oscillograms facilitated the estimation of the deformation levels and establishment of the law of statistical distribution of stresses arising in these zones, dependent on the particle size distribution of the rocks. The verification of the distribution, carried out using Kolmogorov's criterion, showed its correspondence to the normal law.

From the obtained data, it is established that the presence of pieces with diameter $d_p > 0.6b_w$ (b_w - bucket width of excavator) has a great influence on the loading of the excavators. When a bucket of an excavator encounters such a piece of rock, a sharp increase in effort is made on the haul and lifting cables. With an increase in the yield of such pieces, the level of stresses in the zones of formation and development of cracks in metal structures (flange joints of walking excavators' booms and reinforcement of the truck frame of open-pit excavators) is significantly increased. These stresses in most cases reach critical values, leading to an increase in crack-like defects allowed by the guide on defectoscopy of excavators [23] and conditionally on research of cracks. The stress intensity factor (K) in this case exceeds the threshold value, i.e, KI > Kth [24, 25]. The stress intensity factor (K) is a characteristic of the material describing the stress-strain state at the crack tip, at which the rate of its development can be considered to be minimal within the error limits. Therefore, a piece with a diameter $d_p > 0.6 \cdot b_w$, was considered to be sub-standard. In the process of excavating such a piece, depending on its size, 3 to 7 loading peaks arise, which can be regarded as loading cycles. Based on the information on the number and size of sub-standard pieces, the frequency and amplitude of the loading cycles were determined.

The number of unconditional pieces depends on the average diameter of the rock piece in the collapse, it can be calculated in accordance with [18] (Figure 2).

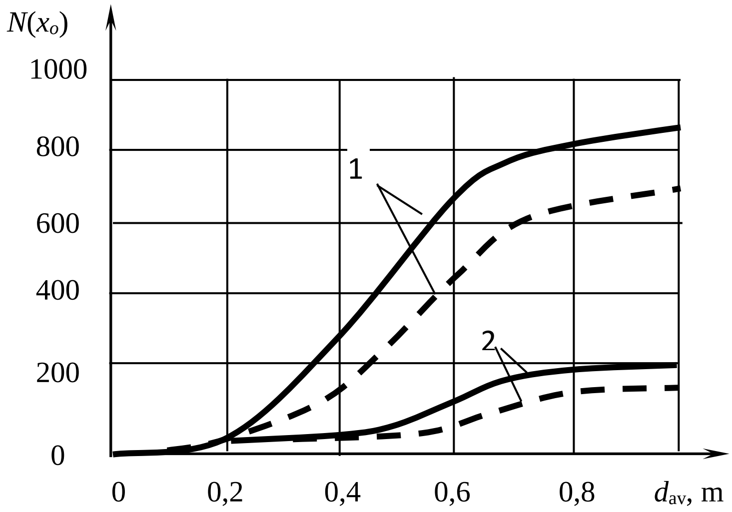

Figure 2. Yield fraction of sub-standard pieces versus the particle size distribution:
1 – + $x_o = 0{,}6 \cdot b_к$; 2 – + $x_o = 0{,}7 \cdot b_к$; (Solid lines – ESH 13/50; Dotted lines – EKG-15(18)

According to the method presented, the approximation of empirical distributions of the diameter of particles of geomaterials is an exponential law with a density:

$$f(\mathrm{x}) = \frac{e^{-\frac{x_o}{M_1}}}{6M_1}. \tag{1}$$

For the case of rock particle distribution along the diameters, the number of pieces of the fraction + x_0 can be determined by:

$$N(\mathrm{x_o}) = 5V \frac{e^{-\frac{x_o}{M_1}}}{6M_1} \tag{2}$$

where V is the total volume of all particles of the disperse system, in this case it can be considered to be equal to the volume (in m^3) of rock mass processed by an excavator per hour and equals the technical productivity of the excavator Q_t multiplied by 1 hour; M_1 - the moment of the diameter of the particles (pieces in the collapse of rocks). M_1 can be expressed in terms of the average diameter of a piece in the decomposition, which is equal to 0.25 d_{av} [18].

5. Conclusions

According to the obtained data on the stressed state in the hazardous zones of the metal structures of the excavators and the values of the range of the stress intensity factors for the allowed crack-like defects, the crack growth rates and the durability of the structure were calculated. As a result, dependencies were obtained between the technical productivity of excavators and the growth rate of typical cracks in the metal structures of excavators, which made it possible to evaluate the remaining fatigue life of the metalwork of excavators in terms of their productivity, depending on the geomechanical conditions of the faces (particle size distribution and yield of the substandard piece) (Figure 3).

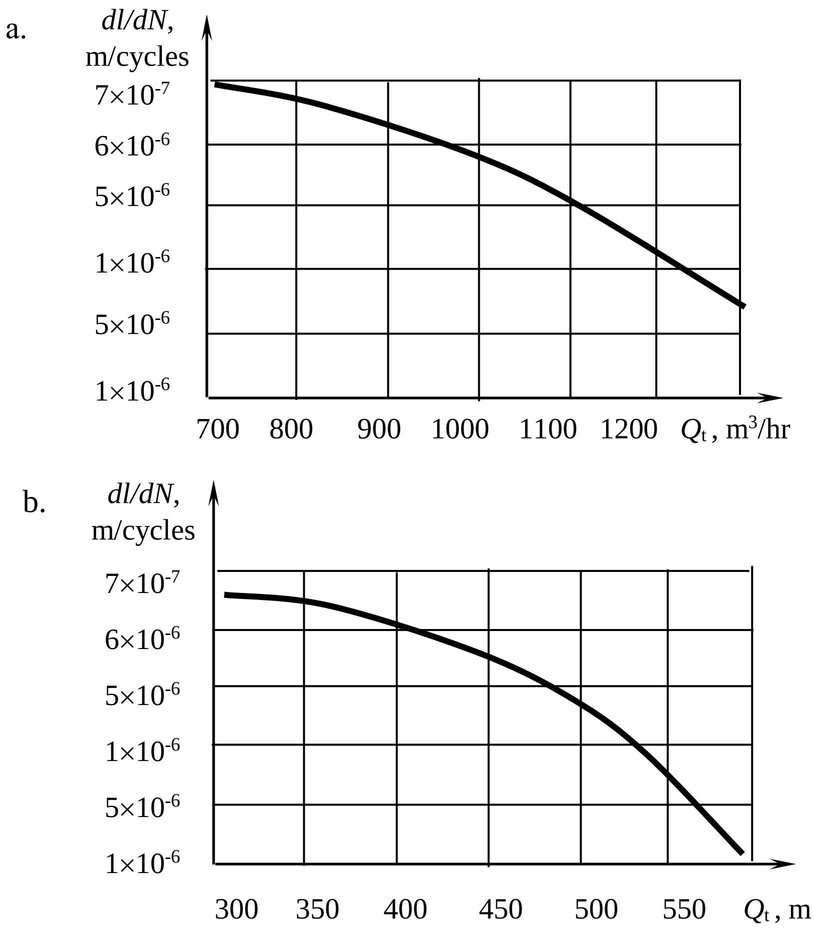

Figure 3. Crack growth rate in hazardous areas against the technical performance of excavators: a – in reinforcement zone of undercarriage of EKG-15(18) excavators; b – in flange joint zones of ESH 13/50 excavators.

The obtained research results can be used to control the durability of metal structures of excavators, the regulation of interrepair times, the prevention of emergency situations and thus the prolongation of their operation periods.

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