Brief destructions of basic nodes of excavators and critical size of cracks

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Abstract. The article studies brittle fractures of metal structures of mine and hydraulic excavators basic units. Based on the data analyzed and physics of the brittle fracture process, recommendations are given to improve the reliability of machines. For the analysis of brittle fractures, statistical data on machine failures under the conditions of the Korshunovsky GOK and ALROSA quarries were used. The approach to the control of nucleation and formation of brittle fractures by non-destructive methods, which substantially reduces the costs of repair works is described. The analysis of brittle fractures of mining excavators basic units revealed general patterns of destruction causes. Accurate identification of brittle fractures requires simplification of repair works. The method of non-destructive control of machines should be applied. The non-destructive control method is used to control the brittle cracking in advance and eliminate during scheduled repairs. The scheduled identification and elimination of cracks reduces laboriousness of repair and recovery operations of large-sized units and aggregates of excavators.

1. Introduction
The technology of minerals extraction in the CIS countries is based on the use of overburden and mining machines with a large unit capacity [1]. The studies were conducted under the conditions of the Korshunovsky GOK and ALROSA quarries on EKG-8I, EKG-15, EKG-10 excavators, H285S hydraulic machines, and L1100 loaders [2]. More than 400 brittle failures of the basic units of machines were analyzed. 86% of failures were identified in winter when the equipment was affected by low temperatures; in spring and autumn, there were significant daily temperatures fluctuations. This can be seen from failure distribution diagrams for the mining excavators main types (Figure 1).

2. Materials and methods
The results of the analysis of brittle fractures of basic units of mining excavators presented in Figure 2-4, revealed general patterns of failure causes. The main causes are stress concentrators (welds), sudden changes in the cross-section of units, structural pads, etc. They account for up to 30% of failures. Up to 75% of failures are caused by typical and repeated failures of the EKG-15 handle (Figure 2), cracks are observed on the front wall of the bucket to which the teeth are attached.
Regardless of the machine design, the number of failures in winter compared with that in summer increases by 3-5 times [3]. This confirms the need to analyze the causes of this phenomenon and develop measures to protect machines from brittle fractures.

The main causes of brittle failures are accidental overloads, a reduced bearing capacity of structures and transition of metal parts to a brittle state due to low temperatures and fatigue phenomena [4]. The failure of the tension axis of the EKG-8I (Figure 3) is caused by an increased stress concentration in places of sharp changes in the cross section of the unit.
Figure 3. Typical fracture of the tensile axis of the EKG-81 excavator.

In hydraulic excavators, 40-60% of failures (Figure 4) occur in the central part of the boom and welded technological holes.

Figure 4. Diagram of the location of brittle failures in the boom body of the H285S excavator.

3. Results and discussion
Failures of large units are caused by complex repair works. Repair works are the most time-consuming auxiliary process in mining enterprises. It accounts for up to 70% of all auxiliary works aimed at restoring basic units of metal structures of excavators. The share of repair personnel at iron quarries is 18%, at coal mines, it is 23%. The labor costs account for more than 20% of the labor costs. The level of mechanization is low - the share of manual labor is 76%. 15-40% of the total number of machines are used for repair works. In cold climate areas, repairmen are engaged in unscheduled repairs, while the costs of repairs are two times higher than those in warmer regions. At the ALROSA enterprises, 35% of the total number of personnel are engaged in repair and maintenance works [7, 8]. The share of machinery and equipment maintenance costs in production costs is 17-
43% [8]. All this increases the relevance of the search for the relationship between brittle structural failures and climatic environmental factors, fractures and critical sizes of brittle cracks, sudden failures and complexity of repair works.

It is known that brittle fracture is preceded by plastic deformations which manifest themselves in the nucleation and motion of dislocations. The motion of dislocations is inhomogeneous and can be inhibited inside the crystal. This causes a concentration of stresses in the local structure, reaching the theoretical strength which causes micro-fractures and cracks with subsequent brittle failures of the structures. The merging of numerous elementary failures leads to the formation of brittle failures and cracks. In general, destruction is the kinetic process that develops in the body of the destroyed structure from the moment of the load application. 90% of the time before destruction is spent on the incubation period associated with the nucleation and formation process of the main crack [9, 10]. The behavior of the metal depends on the load which forms local stresses occurring at the fracture top. The state of the body can be determined by the least durable part of the crystal, its weakest link. Brittle failures are a type of general failures in which the non-standard failure growth is observed at stresses less than the yield strength. The Griffiths’ energy criterion for brittle failures and its modification are fundamental in fracture mechanics [11]. Brittle failures occur when the stress intensity factor, or the rate of release of the strain energy reaches a critical value. In this case, the fracture propagation velocity can reach 1500 m/s [10]. The cracking rate depends on a temperature. At positive temperatures, dislocations follow an increase in a load causing plastic deformations. With a decreasing temperature, the movement of dislocations slows down and they cannot keep up with the shear of plastic deformations. Dislocations accumulate causing critical stress concentrations in local objects; centers of the brittle failures appear [12]. The delay of movement of dislocations occurs under low temperatures or sharp changes in their values. High speeds of brittle failures are due to the fact that at lower speeds the stress is localized by plastic deformations.

The overall picture of brittle fracture can be represented as follows. Under loading, plastic deformations occur as movements of dislocations and development of germainal submicro-fractures. In case of violation of the normal course of plastic deformations under the influence of low temperatures and loads, stress concentrators of micro-cracks turn into trunk ones with a high concentration of stresses at the fracture top. This causes spontaneous opening of the crack. The brittle fracture is characterized by instantaneous crack opening as a result of inhibition of dislocation movements.

The complexity of accurate identification of the moment of brittle fracture makes it difficult to find ways to reduce the complexity of repair works. The non-destructive control method is suitable under these conditions. The non-destructive control method is used to pre-control the brittle crack spreading and eliminate it during scheduled repairs. If there are signs of cracks in the supporting metal structures or welds, an additional check is carried out using such methods as ultrasonic monitoring or penetrating substance monitoring. The first one is based on the ability of ultrasonic vibrations to propagate in solids without noticeable attenuation and be reflected from the interface between the two substances. It is the most reliable and simple method for the defectoscopy of critical parts and welded joints of excavators.

There are five ultrasonic control methods: shadow, resonance, impedance, free oscillations and echo methods. The use of ultrasonic phased arrays is promising. Their main advantage is the ability to generate radiation patterns of the ultrasonic unit, including a focusing, a point and an entry angle which allows you to implement all the control circuits used in multi-element systems with linear scanning: for example, the X-32 flaw detector has a clear interface; its numerous functions facilitate and optimize the control process. The penetration control is designed to determine the location of surface defects with an open cavity, their direction, extent, nature of development. The acoustic emission control of the main bearing elements of the excavator body is aimed at identifying weld defects developing during the operation period due to the accumulation of stresses as a result of cyclic operations. The acoustic emission control identifies potentially dangerous places. When a crack is identified, its critical length can be calculated by formula (1) obtained on the basis of the energy criterion for a local fracture

\[ l = l_0 (1 - 4F(P))^{-1} = l_0 \left(1 - 4J \frac{3E}{2\pi D^2}\right)^{-1} \quad (1) \]

where \( F \) is a function depending on the load related to the yield strength; \( E \) is the modulus of elasticity; \( l \) is the crack length; \( E \) is the Young's modulus; \( J \) is the Griffiths’ energy criterion or the Cherepanov-Rice criterion.

The maximum permissible (critical) crack length \( l_0 \) at load \( P \) is determined by the Griffiths’ formula.
\[ I_{BP} = \frac{2GcE}{\pi P^2} \]  

where \( P \) – the value of the applied load; \( Gc \) – the shear modulus [11].

Restoring parts makes it possible to use their material, shape and residual durability which reduces the consumption of spare parts, labor, energy and materials [6]. When restoring a unit, the following factors must be taken into account: materials of the welded structure, welding materials, welding and auxiliary equipment, types of a welded joint, methods, welding parameters and modes, and qualifications of welders. Only the unconditional fulfillment of all the requirements and the interdependence of factor relations allow us to produce defect-free welded joints. Choosing a wrong parameter, we can create defects in welded joints [5] which may cause failures.

4. Conclusion
Prediction of the development and growth parameters for potential failures by non-destructive control methods is possible [9]. The introduction of equipment diagnostic systems can significantly reduce the probability of emergency failures [13], reduce operating costs, extend the life of machines, and reduce the duration and costs of repair works. The machine can be removed from the operating mode and repaired under reduced complexity and costs of repair works.

In general, the brittle fracture is a multifaceted process that depends on many factors: quality of the material, design of machine components, air temperature and humidity, stress concentration and external loading. Each of these parameters can manifest itself as the main one determining the moment of destruction or accompanying it. Failures occur without exceeding critical load parameters.

5. References
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