Integral criterion of mining machines technical condition level at their operation

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Abstract. Nowadays classification of systems of equipment maintenance and repair (M&R), in particular, mining machines, has a wide range. However, existing systems of maintenance and repair have their own disadvantages like resource-intensiveness and cost, lack of guarantees to prevent emergency failures. In order to reduce the costs for carrying out M&R, the service system CM&R (Conscientious Maintenance and Repair) was offered, which is focused on the tendency to achieve zero emergency failures, to reduce costs and to achieve the maximum possible effectiveness of the object functioning in actual operating conditions. A unified integrated indicator of the degree of object’s degradation has been offered.

Keywords: integrated index, maintenance and repair, service system CM&R, transportation and installation unit, erector, mining machines.

1. Introduction.
The growth of technologies in a hoist equipment sector, and especially in hydraulic, is rapid. This primarily refers to excavator building. This technological outbreak generates competition, which is from year to year becoming more acute and becomes the reason for the appearance on the market of all new models and modifications of machinery. In real conditions of open-pit mining machinery operation, the concentration of technological machines in close vicinity to working areas makes for a decrease in the rhythm of the work of both excavators and the technological transport that ensures the transportation of mined rock from the face within the technological chain further. This situation is primarily caused by the imbalance of organizational and technical measures during operations with a variety of their manifestations in specific situations. Autonomy and maneuverability of hydraulic excavators determine their effective application in difficult conditions for face development in relation to a wide range of properties, both minerals of extracted and excavated rocks.

Alongside with rope shovels (EKG type), hydraulic excavators of the USA, Germany and Japan firms (Caterpillar, Orenshtein & Coppe, Hitachi) are successfully used: EG-5,5, EG-110, EG-150, EG-350, EG-550, PC1250-7, PC3000-6, PC4000, PC8000-6, EX1200, EX1900, EX3600, EX 5500, R984, R994, R995, R996, RH40-E, RH90-C, RH120-E, RH200-E, RH400, 365C FS, 385CFS, SAT-5230, RH-170 and EX-3500 with a load-carrying capacity to 100 t.

The influence of manufacturing and installation technology has a greater importance in the resource of excavator units and parts.

The determining influence on the service life of excavators is exerted by external factors: mining-and-geological, mining-engineering, climatic, quality of face and rock mass preparation, excavator
control quality, organization of mining, system and the level of technical service, which determines its technical condition.

The development of the mining industry is possible not only through the development of fundamentally new mining machines and complexes, but also by upgrading existing equipment and extending its service life [1, 2]. Mining equipment is operated in arduous conditions at open-pit and underground mining; therefore, preventative measures should be taken in time to prevent malfunctions.

When operating a mining excavator, in order to maintain a given level of its reliability, it is necessary to implement strictly the measures provided by the maintenance technology, which entails an increase in costs, the higher the level of required reliability of the units [3].

2. Strategies for maintenance of complex technical systems.

Natural aging of the mining equipment is accompanied by a process of loss of its original characteristics. Maintenance allows keeping and restoring the required level of reliability of objects through the organization of periodical inspections of objects, repair and replacement of some elements, parameter adjustment and elimination of detected faults.

Equipment facilities operating at the mining enterprises are complex technical systems of hazardous production objects, one of the elements of which are the machine units, the safety of technological processes of minerals mining depends on their technical condition.

The decisive influence on the life of machinery primarily is external factors: operating conditions, quality control, system and the level of technical service, determining its technical condition. Carrying out maintenance and repair (M&R) is based on the use of three basic schemes (strategies): maintenance on the fact of failure, preventive maintenance and maintenance on the state.

In modern practice, when a failure of the unit or structure does not cause significant impacts and remediation is simple – approach repair Run-to-Failure (RtF) or Run-to-Breakdown (RtB) prevails. This system is also known as reactive maintenance; it is the easiest maintenance system however, its application is not acceptable for complicated and heavy-duty mining equipment.

The necessity to prevent sudden failures due to breakdowns and accidents led to the emergence of the preventive maintenance system and scheduled preventive repair (SPR) systems. The essence of this approach is to carry out M&R before failure, thereby improving the technical condition of the equipment and reducing the likelihood of failure. As a result, the volume and number of operations at SPR increases. SPR system is the most prominent representative of preventive maintenance (PM) strategies in the planning of services for operating time. In practice, the value of the operating time has become a determined calendar interval, and the moment of M&R carried out on reaching a certain operating time of equipment (Time-Based Maintenance – TBM). Modern automated control systems of M&R have appeared – so called CMMS- and EAM-systems (Computerized Maintenance Management System and Enterprise Asset Management) in particular the well-known – the TRIM EAM-system. However, these systems are far from perfect. Their main disadvantage is resource-intensiveness and cost, with no guarantee of preventing emergency failures [2].

Condition-Based-Maintenance (CBM) is a more progressive system of M&R and comes down to minimize failures through maintenance by the results of state monitoring and technical diagnostics using non-destructive testing equipment. A lean manufacturing system (Lean Production) is built on CBM principles, designed to remove all types of losses. Such systems of lean production as 5S, TQM, JIT, and TPM are widely known. However, preventive maintenance is hard to implement due to the complexity of effective systems of diagnostics of numerous parameters and significant investment in the instrument database, information processing systems, and personnel.

The next steps are the maintenance systems, focused on reliability (Reliability-Centered Maintenance - RCM) – strategy for the prevention of failures, which can cause only significant consequences; and RCMII (Risk-Based Maintenance - RBM) – evaluation and comparison of risks: a reduction of the effects of risk through M&R, or the adoption of risk and rejection of M&R. In other words, the maintenance of a piece of equipment in perfect condition is not a goal in itself; the aim is to
ensure the reliability of the operation processes critical to the system, or to the part of it. In this case, although the direct costs of M&R are reduced, this approach is not conceivable without a wide range of diagnostic procedures of the process equipment. To find reserves for reducing costs for M&R, in the first place, it is necessary to ensure transparency and validity of the repair program. In other words, the cost of repair is justified, when one realizes that it is impossible to spend less because the effects of these savings will be much more expensive than the actual savings or a decision in a reasonable risk.

In contrast to the lean manufacturing systems and RCM, the CM&R system (Conscientious Maintenance and Repair) focuses on the pursuit of zero index crashes, increasing the reliability of the equipment, reducing maintenance and repair costs, increasing the responsible interest and integrity of personnel to ensure the efficient functioning of the object in the equipment technological chain, including the maintenance and repair activities [4, 5]. This takes into account the qualification and promotes the complex system of man-machine effectiveness. These problems, in view of the theory of constraints, force the system to look for solutions to improve their efficiency. The CM&R service system relies not only on a strict technical process, but also on its conscientious implementation. The concept of this system is based on a constant striving to eliminate risks hindering the efficiency sustaining complex system (object or process with the participation of people) in its actual operation conditions in accordance with GOST 27.002-89, GOST R 27.002-2009 (Russian state standard). Natural aging process is the main external factor here. According to this approach, the task of M&R service is to not only eliminate the breakdowns, but also find their causes and prevent problems.

3. An integrated approach to the assessment of technical conditions.
Most recognizable defects that may occur in the aggregate have a certain diagnostic features and parameters, warning that defects exist, develop, and can lead to failure [6]. Through monitoring the various parameters that characterize the operation of the equipment, it is possible to detect a change of its technical condition in time and to carry out maintenance only when its parameters are going beyond the maximum permissible limits [7, 8].

In modern conditions, the problem of industrial safety requires the use of integrated criteria to identify the current technical condition and residual life of machine units, the failure of which could lead to accidents involving significant damage. As a generalized indicator, in our opinion, it is advisable to use the integrated index, obtained by a comprehensive assessment of the current technical state of the object during diagnostic procedures that evaluate the expression (1).

$$\Delta = 1 - Q,$$  \hspace{1cm} (1)

where $\Delta$ – object degree of degradation; $Q$ – integrated index of the object state.

In turn, the integrated index of the state of the object is determined by the average value given to the base value of individual diagnostic indicators based on their weighting factor (2).

$$Q = N^{-1} \sum_{i=1}^{N} \left[ q_i \right] \alpha_i,$$  \hspace{1cm} (2)

where $q_i$ – i-th value of a single indicator obtained by the results of diagnostic procedures; $\left[ q_i \right]$ – basic value of the i-th unit of the diagnostic parameter corresponding to the new object; $N$ – the total number of diagnostic indicators; $\alpha_i$ – weighting coefficient of i-th index. It should be kept in mind that the sum of $\alpha_i$ equals one. Single performance indicators should take into account noise and vibration parameters, the temperature of equipment, the value of acoustic emission signal machinery, current-voltage characteristics of the drive motors, run-time to a full stop and a number of others.

This requires a thorough diagnosis of the equipment, and it is desirable to detect all defects affecting the service life, long before the failure to prepare for repair. Prediction is performed during a systematic monitoring to determine the period during which the object will remain operating state. The
results of the diagnosis and control are the basis for a decision on the need in M&R, its time and volume as well as the time of the next technical state control (see Figure 1).

![Figure 1](image_url)

**Figure 1.** Algorithm of depth and performance procedure of $CM&R$. 

### 4. Conclusion.

The foregoing leads to the conclusion about appropriateness of applying the $CM&R$ system ($Conscientious Maintenance and Repair$) – conscientious maintenance of space ground systems. It also concerns the prospect of an integrated approach in the assessment of the technical condition of diverse technical objects and their constituent elements that operate in a single process space.

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