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Diagnostics of heavy mining equipment during the scheduled preventive maintenance

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Diagnostics of heavy mining equipment during the scheduled preventive maintenance

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Abstract. Intensification of production, economic globalization and dramatic downgrade of the workers' professional skills lead to unacceptable technical state of heavy mining equipment. Equipment maintenance outage reaches 84 % of the total downtime, of which emergency maintenance takes up to 36 % of time, that excesses 429 hours per year fr one excavator. It is shown that yearly diagnostics using methods of non-destructive check allows to reduce emergency downtime by 47 %, and 55 % of revealed defects can be eliminated without breaking the technological cycle of the equipment.

1. Introduction

During the USSR existence, breakup and redistribution of the state property to the private the system of scheduled preventive maintenance (SPM) which was one of five-year planning instruments seemed lose its significance. However profound analysis of modern coal mining industry structure shows the same system of management with the only exception that a capitalist country, which Russia definitely is, requires cost saving and profit maximization. Within the last 10 years coal mine staff competence has dramatically decreased, less young and qualified workers as well as middle and top managers are employed [1]. Intensification of production and above mentioned processes caused inappropriate technical state of coal mines' equipment [2].

In 1980–2011, 5 644 electric shovels with bucket capacity from 4.6 to 42 m^3 were delivered to mining enterprises of the Russian Federation and CIS countries, and in 1999–2011, 259 hydraulic power shovels with bucket capacity more 5 m^3 were delivered. Further tendencies are oriented on bringing into service single large capacity power shovels with bucket capacity of 20-55 м^3 [3].

At the moment the main equipment for coal extraction and loading are crawler shovels with electromechanical drive EKG. At the same time the main part of excavator fleet (63 %) includes excavators with bucket capacity of 8–15 m^3 manufactured by OMZ (IZ-KARTEKS, former Izhora factories). In 2016, 80 % of excavators of Rissian mining industry had excessive service life.

2. Problem description

Comparative study of work of more than 200 excavators in Kuzbass – the largest coal mining region in Russia – showed that imported equipment meets the wear norm of 82 % and home produced equipment meets that norm of 110 %. At the same time imported equipment has low variability of meeting the norm, that means that all machines work in the same way, and home produced equipment has high variability. Some of home produced machines over fulfill the norm more than twice but some of them do not meet even a half of the norm. Working experience shows that home produced excavators have significant overcapacity which is designed in and confirmed by record high productivity over fulfilling the performance standards.

Thus the optimal way to increase efficiency of imported machines is their running in strict accordance with manufacturing facility requirements and their efficiency meeting the "origin" norm. Increasing efficiency of home produced excavators can be reached by determining a potential efficiency norm based on the technical state of the machine and by optimizing maintenance processes [4].

3. Theory

Analysis of technical state of more than 300 excavators run at Kuzbass coal mines in 2011–2016, showed that the most part of equipment was run with significant number of major defects (often hundreds of them), and was in inappropriate technical state (more than 86 %). This tendency comes from low quality of equipment maintenance and repair system.

Independent performance records of the equipment at the opencast coal mine Vinogradovskiy (PAO «Kuzbasskaya Toplivnaya Kompaniya») within the period of five years (from February 1, 2012 to December 31, 2016) for five excavators ESh-10/70, ESh-11/70, ESh-13/50 and eight excavators EKG-5a showed the following results. Of the total service time of the excavators ESh (178537.5 hours) 75% of time (134587 hours) they offloaded the rock mass and 25 % or 43950.5 hours they stood idle. Excavators EKG of the total service time (299621 hours) offloaded the rock mass 126461.7 hours (42%), and stood idle for 173159.3 hours (58 %).

All downtime periods can be divided into production and non-production delays. Production delays include all periods of downtime caused by the necessity of offloading the rock mass (maintenance outage, climate-induced outage, operational delays, etc.). Non-production downtime periods are directly caused by absence of necessity in equipment operation and are not connected with any operational factors (reserve, stand-by duty, conservation, writing-off, etc.).

For excavators EKG production delays made 41% and non-production delays made 59 % (101925 hours) of the total downtime. For excavators Esh production delays made 98 % and non-production delays made 2 % (816.5 hours) of the total downtime. Therefore the total downtime of non-production delays at the mining enterprise made 102741.5 hours. The obtained result shows low level of machine work load, i.e. within the period of 102741.5 hours the studied excavator fleet was functional but not needed that in turn points at excessive capacity at the mining enterprise.

The graphs given below represent the distribution of production delays for ESh excavator fleet (Figure 1) and EKG excavator fleet (Figure 2) respectively.

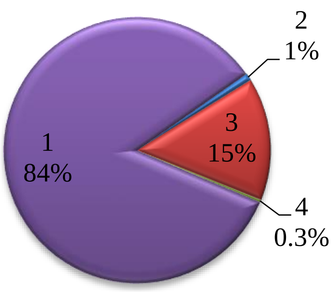

Figure 1. Distribution of ESh Excavators' Production Delay Time: 1 – maintenance outage, 2 – climate-induced outage, 3 – operational delays, 4 – downtime not defined.

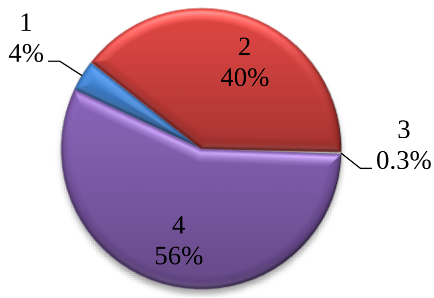

Figure 2. Distribution of EKG Excavators' Production Delay Time: 1 – climate-induced outage, 2 – operational delays, 3 – downtime not defined, 4 – maintenance outage.

Total maintenance outage of the excavator fleet under survey is significant 76338.9 hours. Below, in the Table 1, types and time of maintenance outage (connected with the technical state of the equipment) are listed).

Table 1. Maintenance outage distribution.

Downtime type	ESh, hr.	EKG, hr.
Emergency power cutoff	46.3	74.3
Emergency maintenance	10737.5	14505.3
Yearly maintenance	7322.4	6758.9
Yearly maintenance (nightly outage)	6911.5	6624.0
Diagnostics	23.0	52.8
RGTI shutdown	17.5	5.5
Absence of spare parts (delivery)	1038.4	1791.0
Absence of crane	6.0	185.8
Absence of maintenance fitter	7.8	71.3
Absence of welding specialist	26.0	60.4
Scheduled preventive maintenance	5444.9	5344.4
Scheduled preventive maintenance (nightly outage)	4133.7	4255.0
Prestarting procedures	0	30.7
Preparation for repair	69.0	5.0
Power line repair	248.0	354.4
Rectifying the violations	151.0	26.1
Expert review	8.0	3.0
Total	36190.9	40148.0

Significance of maintenance outage is usually determined by the used repair system. Thus Russian mining enterprises are currently functioning in terms of the Regulation on the Equipment Operation System Based on Scheduled Preventive Maintenance (SPM), introduced in 1983. The main items of the Regulation are in line with the standards set by the International Organization for Standards [5]. According to the Regulation scheduled preventive maintenance is the complex of repeating scheduled and technical activities including maintenance, control and operation of equipment.

In terms of the Regulation there are types of turnaround maintenance: on a shift basis, daily, weekly, on a ten days basis, and season maintenance, and repairs: (capital (C), medium (M), current (Cur), and monthly (Tm)). Regular maintenance on the shift basis is stated as basic preventive activity oriented on significant increase of operating life and presupposed to be performed within the period of shift turnover and within operational downtime periods [6]. Thus an obligatory condition is properly organized shift turnover when an engine operator or a shift man accepting the equipment personally checks its technical state and records detected defects in the shift turnover log, but now it is done only to meet formal requirements, as the staff qualification has dramatically decreased.

Turnaround maintenance is performed in accordance with instructions of equipment producer factories with account for the Regulation. Thus, for example, season maintenance should include probing oils, checking sealing materials of vehicle body, doors etc. All detected failures and defects are subject to registration, and their particular reasons must be revealed. Those failures and emergencies that cause shutdown of equipment for the period exceeding three days must be investigated by a commission with drawing up an Act [7], but this is also done only to meet formal requirements.

Repair frequency should be set due to component life measured in equipment running time units. For example, excavators it is measured due to the amount of processed rock mass in thousands of m^3, and coefficients are calculated with regard for actual operating conditions.

Distribution of Esh and EKG excavator fleet of the opencast coal mine Vinogradovskiy of PAO Kuzbasskaya Toplivnaya Kompaniya is presented on the graphs of Figure 3, Figure 4, Figure 5 and Figure 6, and on Figure 4 and Figure 5 categories of other downtime types, making insignificant 1% of total downtime, are given separately.

The most significant are: emergency downtime periods (ESh – 30%, EKG – 36%), nightly outage during yearly and scheduled maintenance (ESh – 19% и 11%, EKG – 17% и 11%), absence of spare parts (ESh – 3%, EKG – 4%).
On the assumption that the SPM system allows reduction of duration for all repair types due to unit replacement and multishift repair works with fulfilling the discrepancy list and repair works during the night shift, it is possible to reduce downtime periods of the fleet by 21924.2 hours within five years.

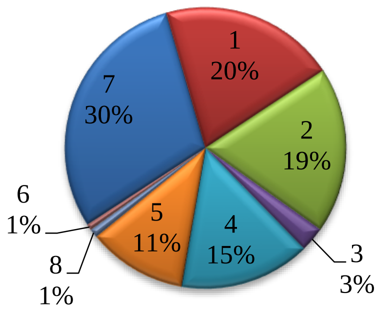

Figure 3. Distribution of ESh Excavators' Main Maintenance Outage Time: 1 – yearly maintenance, 2 – yearly maintenance (nightly outage), 3 – Absence of spare parts (delivery), 4 – Scheduled preventive maintenance, 5 – Scheduled preventive maintenance (nightly outage), 6 – Power line repair, 7 – Emergency maintenance, 8 – Other.

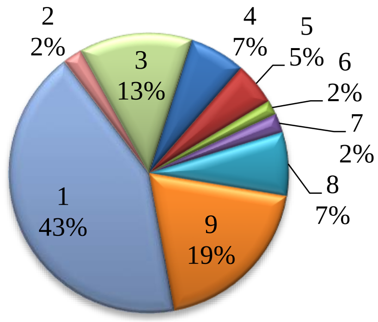

Figure 4. Distribution of ESh Excavators' Other Maintenance Outage Time: 1 – rectifying the violations, 2 – expert review, 3 – emergency power cutoff, 4 – diagnostics, 5 – RGTI shutdown, 6 – absence of crane, 7 – Absence of maintenance fitter, 8 – Absence of welding specialist, 9 – preparation for repair.

Downtimes due to absence of spare parts are caused by inappropriate planning of repair and breaking logistics back. The problem is solved by profound check, repair planning and, for the most part, by bringing the order in the supply service.

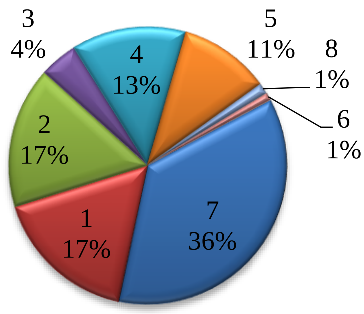

Figure 5. Distribution of EKG Excavators' Main Maintenance Outage Time: 1 – yearly maintenance, 2 – yearly maintenance (nightly outage), 3 – absence of spare parts (delivery), 4 – scheduled preventive maintenance, 5 – scheduled preventive maintenance (nightly outage), 6 – power line repair, 7 – emergency maintenance, 8 – other.

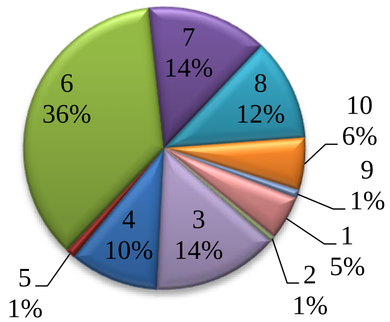

Figure 6. Distribution of EKG Excavators' Other Maintenance Outage Time: 1 – rectifying the violations, 2 – expert review, 3 – emergency power cutoff, 4 – diagnostics, 5 – RGTI shutdown, 6 – absence of crane, 7 – absence of maintenance fitter, 8 – absence of welding specialist, 9 – preparation for repair, 10 – prestarting procedures.

In the current SPM system planning of repair is divided into long term (within the five years' period), yearly and current (on monthly basis). Planning is based on norms set by the Regulations and the data about the equipment technical state collected during its operation. In the yearly planning the SPM system presupposes obligatory setting up the periods and the amounts of works according to the discrepancy list and adjusting the amount of work in the current planning due to the technical state of

the equipment. The result of the planning is a five-year schedule of capital, middle and current repair works, annual schedule of current repair works and a monthly schedule [8].
In the view of the above said it can be affirmed that the SPM system is based not only on scheduled replacement of the spare parts but also on permanent control of the technical state: during the shift turnover – with a record in the shift turnover log, and during the planning of middle, current and annual repair works. Thus the discrepancy list, being an essential part of SPM is one of the most important documents, and the balance of the whole system depends on its proper drafting.

4. Experimental results

In order to reduce emergency downtime since 2012, on the excavator fleet under survey once a year before annual repair works complex diagnostics was performed including the diagnostics of rotating and electrical equipment, and of metal structures, according to maintenance requirement cards worked out due to producer factory technical specifications. The diagnostics was performed in 323 test locations on excavators EKG and in 393 test locations on excavators ESh by using visual and dimensional test (V&DT), vibration-based diagnostics and heat monitoring. Average time of diagnostic works on the equipment was 12 hours, and the report comprises more than 250 pages.
Due to internal organizational problems of the enterprise not all detected discrepancies were fully eliminated. On the one hand that allowed to reduce downtime to acceptable values, on the other hand it allowed to carry out an experiment with monitoring time and conditions of development of different defects to an emergency shutdown.
Figure 7 shows a graph (averaged readings of the whole EKG and ESh excavator fleet under survey) which allows to evaluate the efficiency of such tests, and the difference between the trademarks ESh and EKG did not exceed 2 %.

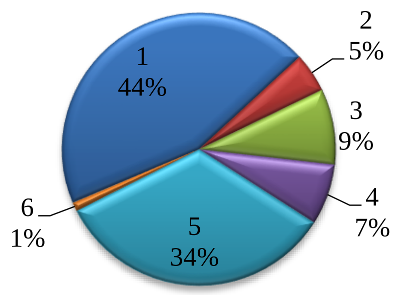

Figure 7. Distribution of the Main Downtime Causes During the Modelling of the system: 1 – detected, 2 – replaced / detected before replacement, 3 – replaced / not detected before replacement, 4 – regular check was not performed, 5 – not detected, 6 – other.

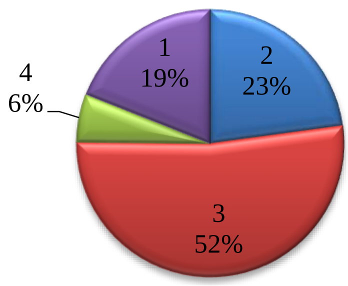

Figure 8. Distribution of Other Downtime Causes During the System Modelling: 1 – absence of access, 2 – detected during the initial check, 3 – power line, 4 – production delays.

On the Figure 8 other insignificant causes of equipment downtime are presented. They make only about 1 % of the total downtime. A modeled situation "What would happen if all major defects were eliminated" allowed to reveal the following categories of defects that had caused emergency equipment shutdowns. The category «Detected» – conclusions comprise defects the early elimination of which would have prevented emergency repair. The category «Regular check was not performed» – annual diagnostics had not yet been performed at the moment of emergency repair. The category «Not detected» – the conclusions do not comprise revealed defects the early elimination of which could have prevented emergency repair.

The category «Power Line» – downtime could not have been detected during the diagnostics due to a voltage slump. The category «Absence of access» – downtime in the nodes unavailable at the moment of diagnostics. The category «Production delays» – downtimes due to the causes that could not have been revealed by way of non-destructive control, like pneumatic system heating. The category «Replaced / detected before replacement» includes downtime periods connected with repeated defects of the spare parts which had been replaced more than one a year. That was why it had not been tested (ropes, teeth, high-voltage cable (often worn out), less often – engine, bucket, etc.). Before their replacement the conclusion comprised defects the early elimination of which could have prevented emergency repair. The category «Replaced / not detected before replacement» is identical to the previous one, but before its replacement the conclusion did not comprise defects the early elimination of which could have prevented emergency repair. The category «Detected during the initial check». The category “Detected by the initial check – defects on the spare part had not been revealed, but emergency repair could have been prevented by the initial check of the spare part.

5. Discussion

The modeled situation showed that 44 % emergency delays could have been prevented only by a diagnostic check performed only once a calendar year. More 3.08 % (43% of the category «“Regular check was not performed») could have been avoided if regular annual check is strictly performed once a year, that will make almost 47 % or 11943 hours provided that this method of diagnostics is used. It is 1038.5 shifts of excavator fleet work within the period under survey or 17.3 shifts per unit of equipment within a year. Downtime of the excavator fleet within the period under survey is presented in Table 2.

Table 2. Modelled time of excavator fleet downtime.

Detectability criteria of defects	Emergency outage, hr.
Detected	11071.5
Detected during the initial check	59.0
Replaced / detected before replacement	1198.4
Replaced / not detected before replacement	2288.6
Check was not performed	1850.5
Power line	135.0
Not detected	8575.7
Production delays	15.0
Absesnce of access	49.1
Total	25242.8

As 93 % of discrepancies detected by diagnostic tests within a period of time cause an emergency shutdown (Figure 9), one of the most important results of diagnostic testing is the reduction of emergency downtime. It allows not only increase productivity rate due to more time available and reduce repair expenses, but also plan the equipment work load more effectively because failures in work performance caused by unplanned downtime are avoided, and that in turn allows to increase workforce productivity.

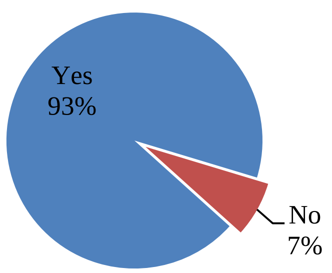

Figure 9. Percentage of Defects Causing Emergency Shutdown of the Excavator.

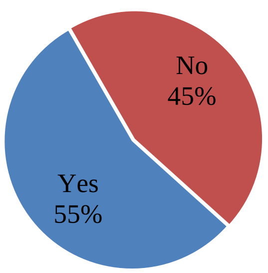

Figure 10. Percentage of Defects Repairable Without Equipment Removal from Service.

The second by significance is the fact that the amount of defects that must be eliminated during forced idle hours by efforts of the brigade without breaking the technological cycle of the equipment makes 55 % (Figure 10).

A significant number of defects revealed during annual diagnostic tests are accumulated within a long period of operation. Year after year these defects accumulate due to violation of the shift turnover norms and absence of maintenance on the shift, day, week, ten days' basis and season maintenance. At the best case it is limited only to cleaning and oiling. Capital, current and monthly repairs are performed in order to eliminate only emergency failures evidently being a threat of soon emergency shutdown of the equipment.

Therefore the SPM system requires long-term and short-term planning. It is based on scheduled repair works with regard for the actual technical state of the equipment at every moment of time according to the discrepancy list drafted by a qualified specialist. In the circumstances concerned it becomes clear that significant emergency downtime periods of the equipment of Kuzbass opencast coal mines are nothing less but major violation of the SPM system regulations. But it does not cancel the need of it modernization to the system of repairs due to actual technical state of the equipment. In practice it leads to even more profound diagnostic testing based on modern methods of non-destructive testing for long-term prediction of residual operation life in order to break from one of the most economically ambiguous aspects of SPM – keeping a large repair parts stock based on calculating nodes' non-failure operation time.

6. Summary and conclusion

The performed analysis of the excavator fleet downtime and annual diagnostic testing allowed to come to the following conclusions:

1. Inappropriate technical state of the equipment is caused by incorrect use of the SPM system in what concerns low service standards and incorrect evaluation of actual technical state.
2. Maintenance outage of equipment reach 84 % of the total downtime of which maintenance outage takes up to 36 % exceeding 429 hours per year for one excavator.
3. More than 93% of defects in excavator will cause emergency shutdown in the long-term prospective.
4. Diagnostic tests performed at least once a year allow to reduce emergency downtime by 47 %, and 55 % of revealed defects can be eliminated without breaking the technological cycle of the equipment.

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