ANALYSIS OF THE EXPLOITATION OF DEVICES OPERATED IN THE MINING INDUSTRY IN THE ASPECT OF THE QUALITY IMPROVEMENT OF TRIBOLOGIC CENTRES

Key words
Exploitation, excavator, loader.

Abstract
The problem of the quality assessment of tribologic centres illustrated with an example of excavators and loaders operated in open pit mines is presented in this study. The analysis comprises the identification of “weak centres” and the proposition of both constructional and operational modernisation executed in order to improve quality. The device quality assessment can be executed via assessment of the value of proposed set of reliability-exploitation factors.

Introduction
Excavators and loaders used in mining industry are the subject of the examinations. These machines are classified as reparable objects with determined operation cycles. Exploitation conditions of theses objects can be
considered as heavy (21 to 24-hour operation and great dustiness due to the rock material). Exploitation problems also result from ecological purposes, including significant contamination of the environment, oil and grease effluents, the necessity drain contaminated water from excavations and seismic influence onto buildings located near mines.

Exploitation quality is a set of features formed in whole cycle of the object’s existence, and they are considered basic assessment criterion. The exploitation comprises actions from marketing recognition and preliminary project to the object production and exploitation phases.

Table 1. Excavators and loaders used in Kielce Mineral Resources Mines

<table>
<thead>
<tr>
<th>Technical Data Name</th>
<th>Production date, manufacturer</th>
<th>Bucket capacity [m³]</th>
<th>Motor power [kW]</th>
<th>Excavator mass [t]</th>
<th>Main motor power [kW]</th>
<th>Rotation motor power [kW]</th>
<th>Pressing motor power [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brawall excavators 1611</td>
<td>1993, 1995, Poland</td>
<td>2</td>
<td>132</td>
<td>-</td>
<td>32</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electric excavators E-302, E303</td>
<td>1977, 1981, Poland</td>
<td>3</td>
<td>130</td>
<td>115</td>
<td>130</td>
<td>60</td>
<td>57</td>
</tr>
<tr>
<td>Loaders CAT 966G</td>
<td>1996, USA</td>
<td>3.5</td>
<td>174</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Quality requires consideration of specific factors in the cycle of the object’s existence. In the tested case, these essential factors included reliability, compact structure, efficiency, aesthetics, ergonomics, and the ease of access to “weak points.” Exploitation quality depends both on the product quality and service quality. With respect to frequency of major failures in the operation of the tested objects and the demand for high efficiency, quality factors taking under consideration were measured using exploitation costs [2]. This allows the assessment of the object quality in given exploitation conditions, i.e. “effectiveness” being a measure of the object exploitation usability for the realisation of targeted tasks. It is compatible to the classic attitude presented in [1], according to which the exploitation quality factors should be constituted of elements being components of the exploitation usability equation. Obtained
effects (guaranteed by reliability) and exploitation costs are very essential in the case in question. The analysis comprising excavators and loaders used in the Kielce Region Mines of Mineral Resources are shown in Table 1.

The exploitation process assumes that the tested objects operate in a 3-shift system under all seasonal weather conditions. Thus, the operation of excavators and loaders takes place during all three shifts. Average nominal operation time during single shift amounts for about 7 hours. Devonian dolomite is excavated, which is previously disintegrated with use of explosives. Rock grain-size, in the case of excavators, does not exceed 800 mm, and these are usually limes of even a smaller grain-size. The loaders are used for loading finished products and semi-product of various granulations, usually up to 200 mm. They are also used for loading the raw material in the excavation (particularly loader CAT 966G).

Problems of work safety and ergonomics are also connected with the machine operation process. Certificates ROPS/FOPS should be mentioned here as follows: ROPS – cabin protection structure in case of the machine overturn, FOPS – cabin protection structure against falling objects. The operator of the Brawall 1611 works in a standard cabin, which is equipped with windows and a heating system. It is not equipped with air-conditioning and ROPS safety devices. Electric excavators E-302 and E-303 have cabins additionally equipped with a grid protecting the cabin against falling material. Operators of Ł-33 excavators work in a standard cabin, which is made of square-section tubing, and the cabin is closed and covered with sound-insulation material and equipped with windows and heated with an electric heater. The cabin is not air-conditioned and has no additional ROPS protections. CAT 966G loaders have cabins made according to ROPS/FOPS certificates, closed, with grass panels, heated and sound insulated.

The following action units have been distinguished in the machine handling process \( (Po) \):

\[
P_0 = \{ P, \ CO, \ NBW, \ NBZ, \ NPZ, \ NGZ \}
\]  

where:

\( P \) – technical inspections according to technical-operational documentation \( (DTR) \),
\( CO \) – servicing activities according to device \( DTR \),
\( NBW \) – current repairs in own system,
\( NBZ \) – current repairs in ordering system,
\( NPZ \) – extension repairs of vehicles in ordering system,
\( NGZ \) – major repairs in ordering system.

A detailed description of machine handling and technical inspections executed by operators can be found in the DTR of the devices in question. DTR
also contains guidelines concerning machine operations during the breaking-in period, transport and storage instructions, work safety rules, lubrication instructions, fuel tables, grease tables, and exploitation fuel tables.

1. Identification of weak points

In case of the devices in question, the tribology points constitute the weakest points in the object reliability structure. Because of the continuous exploitation in the mining season, the objects in question are characterised with a high failure frequency, which results in machine operations breaks caused by missing reserve devices. It is related to considerable economic losses and hazards related to work safety and ecology (oil, grease and exploitation liquids and effluents into the ground causing contamination of the natural environment having a negative influence on the infrastructure). Based on exploitation data, Table 2 has been prepared indicating the weak points and corresponding

<table>
<thead>
<tr>
<th>Object (vehicle)</th>
<th>Weak points</th>
<th>Tribology points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavators Brawal 1611</td>
<td>Open lubrication system of the bean stroke mechanism</td>
<td>Carriages, slippers</td>
</tr>
<tr>
<td>Travelling systems (for ample travelling reductors)</td>
<td>Gears, Cardan clutches, bearings</td>
<td></td>
</tr>
<tr>
<td>Electric excavators E-302, E303</td>
<td>Caterpillars</td>
<td>Pins, Caterpillar segments</td>
</tr>
<tr>
<td>Pneumatic system (pneumatic servo-motors)</td>
<td>Piston, cylinder, piston rod, gland,</td>
<td></td>
</tr>
<tr>
<td>Main clutches, driver clutches</td>
<td>Inserts, clutch discs</td>
<td></td>
</tr>
<tr>
<td>Arm bushes</td>
<td>Bushes, pins</td>
<td></td>
</tr>
<tr>
<td>Rotation gears</td>
<td>Gears</td>
<td></td>
</tr>
<tr>
<td>Clutch bands of the bucket</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breaking bands of the bucket</td>
<td>Band, drum</td>
<td></td>
</tr>
<tr>
<td>Breaking bands of the travelling blocking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loaders Ł-34</td>
<td>Hydraulic pumps, distributors, servo-motors, elastic cables</td>
<td>Pistons, body, piston, cylinder, piston rod, gland</td>
</tr>
<tr>
<td>Elements of the bucket motion, particularly pins of servo-motor and extension arm</td>
<td>Pins, bushes</td>
<td></td>
</tr>
<tr>
<td>Driver transmission system, particularly front bearings of the drum driving the front bridge and bridge mounting bolts</td>
<td>Differential and planetary Sears, Cardan clutch elements,</td>
<td></td>
</tr>
<tr>
<td>Loaders CAT 966G</td>
<td>Bucket motion system (extension arm, bushes, bucket)</td>
<td>Bushes, pins,</td>
</tr>
</tbody>
</table>
tribology points, which are the direct causes of failures and break-downs of excavators and loaders. Systematic examinations allowing the assessment and the keeping the required level of quality, together with realised improvements of the object and the process of its exploitation, should allow the satisfying of requirements determined in the DTR. The improvements should meet the requirements of EU standards and mining law rules, determined by suitable branch units. In the tested case, periodical assessment of the exploitation quality should be made on the basis of the reliability factor, with exploitation costs taken under consideration.

2. Quality assessment

The object quality assessment should be made with use of the proposed set of reliability-exploitation factors.

The analysis of the machine operation process should be completed using the assessment of the machine functions in the exploitation process. The object quality is determined by the object’s ability to perform the targeted tasks. Parameter of the failure stream can be assumed as the basic criterion.

\[ w(t) = \frac{n(\Delta t)}{N(\Delta t)} \]  \hspace{1cm} (2)

where:

- \( n(\Delta t) \) – number of objects failures between \((t - \frac{\Delta t}{2})\) and \((t + \frac{\Delta t}{2})\),
- \( N \) – number of objects in investigation,
- \( \Delta t \) – time interval.

The proper course of the machine operation process, in practice, is characterised by the assemblage of quantitative parameters. Any deviations and changes in their values should be considered as failure symptoms.

The assessment of the process handling should be based on the analysis of technical servicing. Analysis of proposed assessment factors proved the necessity of taking under consideration the following characteristics, according to commonly used relations the proposed factors comprise:

- Average time of the recovery (depending on equipment quality and technological quality):

\[ T_n = \frac{1}{N} \sum_{n} t_n \]  \hspace{1cm} (3)
where:

\( N_n \) – number of break downs in tested period,
\( \sum T_n \) – sum of recovery times.

- **Shutdowns factor:**

\[
K_p = \frac{T_o(t)}{T_u(t) + T_o(t)}
\]  

(4)

where:

\( T_o(t) \) – Total time of the machine use up to the moment \( t \),
\( T_u(t) \) – Total machine handling time up to the moment \( t \).

- **The object readiness:**

\[
K_g = \frac{T_u(t)}{T_u(t) + T_o(t)}
\]  

(5)

where:

\( T_u(t) \), \( T_o(t) \) – like above.

- **Handling intensity, i.e. number of handlings per time unit of the object’s operation:**

\[
K = \frac{M_n}{T_u(t)}
\]  

(6)

where:

\( M_n \) – number of machine handlings in time \( T_u(t) \).

- **Mean operation time per single handling:**

\[
\theta = \frac{1}{K}
\]  

(7)

The following exploitation tests should be executed in order to assess the object quality and quality of its tribology points: failure analysis including the failure cause, the analysis and assessment of the operation and handling process, the collection and processing of the exploitation data [3], the introduction of modernisation changes improving the machine reliability, and making decisions due to continuation or stoppage of the tests.
Assemblages of activities realised in the scope of undertakings mentioned above should be determined in the form of directives. Their realisation is dependent on real possibilities conditioning the course of the tests. The general concept of the testing program is shown in Fig. 1.

**Summary**

Quality forming complex technical objects, like the tested excavators and loaders, operated under the influence of many forcing agents should be conducted both in the designing and manufacturing processes. Exploitation quality assessment should be made on the basis of the proposed factors, which allows the verification of the machine handling both in qualitative and quantitative aspects. Because of the obtained effects and their costs, the rationalisation of use and servicing processes is very essential for the tested object class. The proposed assessment manner should allow the improvement of quality and reliability of the objects.
References

Analiza procesu eksploatacji urządzeń pracujących w przemyśle wydobywczym w aspekcie poprawy jakości węzłów tribologicznych

Słowa kluczowe
Eksploatacja, koparki, ładowarki.

Streszczenie
W artykule przedstawiono zagadnienie oceny jakości węzłów tribologicznych na przykładzie koparek i ładowarek pracujących w kopalniach odkrywkowych. Analiza obejmuje identyfikację „słabych ogniw” oraz propozycję modernizacji konstrukcyjnej i eksploatacyjnej w celu poprawy jakości. Ocena jakości urządzeń może być dokonywana poprzez oszacowanie wartości zaproponowanego zestawu wskaźników niezawodnościowo-eksploatacyjnych.