Information and diagnostic tools of objective control as means to improve performance of mining machines

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Abstract. The paper justifies the relevance of developing and implementing automated onboard systems for operation data and maintenance recording in heading-and-winning machines. The analysis of advantages and disadvantages of existing automated onboard systems for operation data and maintenance recording in heading-and-winning machines for potassium mines are presented. The basic technical requirements for the design, operating algorithms and functions of recording systems of mining machines for potassium mines are formulated. A method of controlling operating parameters is presented; the concept of the onboard automated recording system for the Ural heading-and-winning machine is outlined. The results of experimental studies of variations in loading of the Ural-20R miner's operating member drives, using the VATUR portable measuring complex, are given. It is proved that existing means of objective control of operating parameters of the URAL-20R heading-and-winning machine do not assure its optimal operation. The authors present a technique of analyzing the data provided by parameter recorders that allow increasing efficiency of mechanical complexes by determining numerical values characterizing the technical and technological level of potassium ore production organization. The efficiency assessment criteria for engineering and maintenance departments of mining enterprises are advanced. A technology of continuous automated monitoring of potassium mine's outburst hazard is described.

1. Introduction
The objectives of increasing production volumes and unit performance of shaft-sinking clearing combines, optimizing the costs of maintenance and repair while reducing the number of emergency failures remain relevant for the enterprises engaged in the underground extraction of potash ore. Currently, there is no systematic approach to address these challenges, making it difficult to implement measures to improve the reliability of mining equipment and the quality of its technical service.

Experience of leading machine-building and mining enterprises shows that increased equipment performance can be achieved through the application of measuring software and recording complexes for continuous control of parameters of the work drives for the winning machines. The implementation of these systems, as well as the rationale for the methods of collecting, processing and further use of the information received, is a complex scientific and technical task that allows us to improve the arrangement of company's engineering and support services, to improve the technological processes of...
production and transportation of fossil, to generate proposals for equipment enhancement, to improve the safety of mining [1].

Currently, domestic shaft-sinking clearing combines Ural equipped with a planetary disk type and auger type actuators and trucks are widely used at the Russian potash mines. Combine actuators are sets of independent mechanical transmission with three-phase asynchronous motors.

Ural combines are successfully used in domestic potash mines for over 30 years and are generally characterized by high reliability. At the same time, the winning machines do not have the effective on-board diagnostic systems, automatic load limit, the regime parameters control and operating time counter, which causes an increase in the probability of machine crashes, in the majority of cases by the fault of the operator. The lack of the on-board monitoring system does not allow one to make a correct assessment of the operational loading of the machine components, to adequately determine the remaining service life of winning machine's parts and to carry out repairs based on the impact of the actual technical condition in a timely manner.

2. Purpose of research
Challenging operating environment for mining machines, complex processes of interaction of machine elements among themselves and with environment, as well as price restraints (profitability, competitiveness of products in the market), necessitated the search for technically simple and reliable solutions when designing automatic systems for control and monitoring the technical condition of mining machines. In our view, one of the most promising ways to control the parameters of work and technical condition of shaft-sinking clearing combines is an analysis of the intensity and nature of external loads determined through measurement of the instantaneous values of currents, voltages and power consumed by electric actuators [2–4].

3. Idea of technical solution
Employees of the Department of Mining and Oil-Field Machines at Perm National Research Polytechnic University, together with the specialists of ‘Regional rope centre’ LLC (Perm), developed a prototype of software and recording complex VATUR, which provides measurement, recording and preserving of the fundamental parameters of shaft-sinking clearing combines' actuators [5].

The structure of recording complex VATUR (Figure 1) includes a processing unit, power supply and switching, current clamp, voltage sensors and displacement. The processing unit consists of a single-board computer and an analog-to-digital converter (ADC). Current clamp provides transformation of input current into an output voltage by ratio 1 : 1. Voltage sensors convert the input voltage in the ratio of 1 : 3. These converted signals are supplied via the ADC directly into the computer. Distometer is made on the basis of incremental turning angle encoder PUF-6 with 360 strokes and vice versa. The distometer is mounted on the side ski of the combine from the direction of the magnetic station. After the measurement, the data are stored on a removable hard disk and then transferred to the office computer.

Software and recording complex VATUR carries out 100 measurements within one 20 ms period of supply mains. The values of effective power $I_{\text{eff}}$, voltage $U_{\text{eff}}$, active $P_a$ and full power $S$ are determined from the measured instantaneous values of current $I_i$ and voltage $U_i$:

$$I_{\text{eff}} = \left( N^{-1} \sum_{i=1}^{N} I_i^2 \right)^{1/2}, U_{\text{eff}} = \left( N^{-1} \sum_{i=1}^{N} U_i^2 \right)^{1/2}, P_a = 3N^{-1} \sum_{i=1}^{N} U_i I_i, S = 3U_{\text{eff}} I_{\text{eff}},$$  \hspace{1cm} (1)

where $N$ is the number of measuring points over a fixed time interval, $N = 100$; time interval is 20 ms.

The supply voltage and the load on the combine engines are symmetrical, so active power measurement in three-phase circuit is made by the active power meter with artificial zero. Visualization and data processing is carried out by means of a specially developed software Vatur-of (Figure 2).
Figure 1. The block diagram of the VATUR measuring system: 1 – power unit, 2 – processing unit, 3 – switching unit, 4 – current sensors (clamp meters), 5 and 6 – voltage sensors, 7 – motion sensor.

Figure 2. Diagrams of active three-phase powers of electric motors of the Ural-20R machine at an average speed of 10.5 m/hour: 1 and 2 – the drives providing the relative motion of cutter wheels; 3 – fender drive; 4 – conveyer drive. Grid line pitch – 5 s.

On the above-mentioned chart of change of active power of the electric drives for cutter wheel relative motion, there can be identified launch areas (A-B), idle move (B-C), cutting (C-D) and steady state operation (D-E). Software and recording complex VATUR allows one to create and store of data arrays containing information about the long periods of work of the shaft-sinking clearing combine [5]. Wattmetrogram analysis using methods of mathematical statistics allows one to determine the following.

1. **Operation specifications of the combine**: turn on-turn off frequency, productive work time and downtime. These parameters characterize the rhythm of technological processes of minerals extraction and transport in the cleaning chamber, allow us to estimate the level of work arrangement and the
degree of equipment utilize capacity, to identify negative trends and factors affecting the performance of the mechanized complex.

2. **The frequency of occurrence and duration of excessive loads**, that characterizes the expertise and industrial practices that are shown by operators of mining machinery. In case of emergency the wattmetrogram is a document that allows us to identify the causes of the accident and to judge the actions of the staff. The automatic load control and combine management systems can operate on the basis of relevant information about the operation of actuators.

3. **The average and peak values of the loads affecting the transmission parts.** The average values of the active power and its fluctuations characterized by a standard deviation allow a qualitative estimation of the dynamic component of the external load, precision of manufacturing and assembly of transmission elements, the intensity of degradation processes in combine actuators. Information on the nature and magnitude of change in actuator load is delivered to the manufacturer for further design calculations, changes in the machine design at the design stage, the modernization of the combines in operation.

4. **Technical performance and service hours of the combine.** The findings correlated with the costs of maintenance and repairs determine the cost of vehicle-hour of combine availability and objectively characterize the efficiency of the enterprise maintenance services. The increase in the cost of vehicle-hour of availability of the particular mining machine compared with the rest of the combine in operation at the mine can reasonably show the necessity of its decommission [1].

5. **The total and remaining transmission elements lifetime.** It is known that the operating time of the mining combine is determined by the strength properties of machine elements, as well as the size and nature of the actual operating loads. Total and residual lifetime of the uniform transmission can be determined with a high degree of probability on the basis of continuous recording of the active power of the engine (its operational load) in a turnaround time according to the procedures detailed in [2-3, 6-7].

A generic parameter that allows us to assess the efficiency of mining machine is the value of specific energy consumption for the process of destruction of potash mass by the combine cutters, which characterizes the physical and mechanical properties of potash mass, work operating parameters and the combine technical condition. The value of specific energy consumption of the process of destruction of the mass by the actuators' cutters was calculated for plots of steady state combine operation according to formula \( H_w = P_a(V_p F_d \gamma)^{-1} \), where \( H_w \) is the specific energy consumption of the cutting process, kWh/t; \( F_d \) is the face area treated by the actuators, m\(^2\); \( V_p \) is the speed of the combine at the face, m/h; \( \gamma \) is the ore density in the mass, t/m\(^3\).

Analysis of the experimental results (Figure 3) showed the ability to identify accurately the change of specific energy consumption of the process of mass destruction by actuators' cutters of the combine. The methods and equipment make it possible to register a decline in the energy intensity of the mass destruction process caused by gas-dynamic phenomena, to carry out the identification of outburst zones, thus ensuring the safe conduct of mining operations [8].

![Figure 3](image-url)  
*Figure 3.* Dependence of change in specific energy costs on the velocity of the Ural-20R machine feed.
Mathematical processing of change functions of the instantaneous values of currents consumed by combine electric motors was carried out using spectral analysis techniques. According the Nyquist theorem, the analogue signal spectrum can be uniquely represented by its discrete samples taken at intervals of \( \tau = 0.5 \frac{1}{f} \), where \( \tau \) is the sampling interval of the analog signal function by time, s; \( f \) is the frequency of the analog signal range limit, Hz.

Spectral analysis of analog current signals (Figure 4) obtained by the measurement software and recording complex VATUR allows to reveal frequency components from 0 to 1000 Hz, characterizing the fluctuations of kinematic chain actuator – gearbox – drive motor. Defects in working units and mechanical gears cause the occurrence of variable loads, which causes the appearance of new spectral components. Periodic measurement of values in the current spectrum that characterizes the specific defects in the drive motor and the manual transmission, allows us to carry out the assessment of technical condition of the drive mining machinery and, if necessary, to carry out repairs to prevent crashes.

**Figure 4.** The spectrum of the current of the drive induction motion relative to the motion of the cutter wheels of the Ural-20R machine (logarithmic scale of amplitude axes).

### 4. Conclusion

By analyzing the consumed current records in asynchronous motors, the defective electric part of the rotor may be found, including the rotor winding breaks and the short circuit of the active core plates; the electrical parts of the stator, including breaks and electrical asymmetry of power winding, the short circuit of the active core plates; static and rotating eccentricities; bearing defects, leading to fluctuations in the air gap form. In addition, an important diagnostic sign is the value and duration of the occurrence of starting current. In the actuators’ transmission the fault gears, the landing gear on the shaft, the misalignment of slave shafts and their rotation bearings, the misalignment of the driven shafts arrayed in a line can be diagnosed by the nature of the current signal changes.

The disadvantages of the method of evaluation of the technical condition of transmissions by current consumption relates the difficulty of identifying a number of defects at the initial stage of development. Primarily, these are the defects of rolling bearings, the identification of which is carried out indirectly, for example, by changes in the characteristics of gearing [9]. The increased information content and accuracy of diagnosis is possible through the implementation of periodic multi-parameter monitoring (acoustic emission, vibration diagnostics) of bearing assemblies.

Continuous recording of capacity consumed by combine electric motors allows the simplest and the most reliable monitoring of the operational load of mining machine's actuator assemblies, carrying out an assessment of technical condition, complete and remaining life of the transmission components [10]; determining the operating parameters, technical performance and the combine error-free running time, improving the safety of mining operations. The combine automatic control systems may effectively operate on the basis of the current information about the amount and nature of actuator load.
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