DOI: 10.31897/PMI.2020.2.234

UDC 622.6-83

# "Ural-20R" combines loading drives evaluation in two-stage development of the face

**Dmitriy I. SHISHLYANNIKOV ✉, Mikhail G. TRIFANOV, Gennadiy D. TRIFANOV**
*Perm National Research Polytechnic University, Perm, Russia*

The technological features of the use of high-performance Ural-20R combines in the conditions of potash mines in Russia are described. It is shown that when the capacity of the worked potash seams is over 4 m, a two-layer ore extraction is used. The formation of cutting process, implemented by the second course of the combine in the treatment chamber, is carried out by an incomplete section of the executive bodies. The standard control system, display and protection of the Ural-20R combine does not allow monitoring and reliable estimation of the magnitude of dynamic components on the drives of the mining machine loads, as well as tracking the feed rate of the combine to the face. The regulation of the operating parameters and the assessment of the degree of loading of the drives of the excavating machine in real time are assigned to the operator.

The fundamentals of the experimental research methodology for assessing the loading of drives of Ural-20R combines with the destruction of the potash mass by an incomplete section of the executive bodies are described. The device and the operating procedure of the "Vatur" software-recording complex, which measures, records and records the electrical parameters of the drive motors of a mining machine, is described.

The process studies results of forming loads on drive elements of Ural-20R combines when mining a face with an incomplete section of executive bodies are presented. It is proved that the work of combine harvesters on the undercut of the formation with a high feed rate is accompanied by significant dynamic loads on the drives of planetary organs and an overload of the drives of the Berm organs, which leads to an accelerated consumption of the resource and emergency failures of the gearboxes and motors of the extraction machine.

***Key words*:** "Ural-20R" combine; loading; drive unit; mode of operation; potash and magnesium ore mining

***How to cite this article*:** Shishlyannikov D.I., Trifanov M.G., Trifanov G.D. "Ural-20R" combines loading drives evaluation in two-stage development of the face. Journal of Mining institute. 2020. Vol. 242, p. 234-241. DOI: 10.31897/PMI.2020.2.234

**Introduction.** Mining enterprises that are engaged in the extraction of potassium-magnesium ores by underground mining are using mechanized combine complexes and a mining development system. One of the largest deposits of potassium and magnesium salts, Verkh-Nekamskoye, is located in Russia, where the highly productive "Ural-20R" tunneling machines manufactured by KMZ JSC (Kopeisk, Chelyabinsk Region) are widely used [3, 8, 13 ].

The manufacturer conducts research and development work to improve the products: the most modern modifications of the "Ural-20R-11/12" combines are equipped with the registration and visualization of current loads of drive motors of rock cutting executive bodies and loading equipment systems. However, the control of operational parameters of the combine operation (feed rate to the face) and the assessment of the load of the drives in real time is performed by the operator [4, 6, 18].

A correct assessment of the magnitude and nature of changes in the loads of drives of mining machines of potash mines allows us to justify the rational parameters of the salt mass destruction process by cutters of the executive bodies of tunneling machines and to minimize the number of emergency failures caused by excess loads [1, 7, 17].

**Operating modes of "Ural-20R" combines.** Under the operating mode of the excavating machine is understood the established order of alternating periods, characterized by the number of starts and shutdowns, the time of technological interruptions and productive work, the magnitude of the loads, as well as their duration and nature of the change over time [5, 12]. The choice of rational operating modes corresponding to the physicomechanical characteristics of the salt mass being destroyed (downhole loads) determines the efficiency of using high-performance mining machines in potash mines and, first of all, their technical productivity. A significant number of random factors affecting the load on the drives of the "Ural-20R" production and treatment combines determines the inevitable occurrence of errors when calculating the instantaneous values of random unsteady

DOI: 10.31897/PMI.2020.2.234

loads in mechanical transmissions of combines, which, in turn, leads to increased accident data of mining machines [2, 11].

The instant load on the drives of the executive bodies of the "Ural-20R" tunneling machines can be mathematically described as the sum of three components:

$$N(t) = N_1(t) + N_2(t) + N_3(t), \quad (1)$$

where $N(t)$ – instantaneous value of the load on the drive of the executive body of the combine; $N_1(t)$ – the component determined by the physicomechanical properties of the destroyed potash mass and the geometrical parameters of the face; $N_2(t)$ – component determined by the technical condition and kinematics of the executive bodies of the tunneling machine; $N_3(t)$ – a component determined by the operational parameters of the "Ural-20R" tunnelling machine, in particular, the feed rate to the face.

The important technical characteristics of tunneling machines with executive bodies of the drilling type are the shape and dimensions of passable workings, since the rational scope of the excavation machines when used in the treatment chambers of potash mines, the magnitude and nature of the load changes on the drive elements, power ratio harvesters and the possibility of using mine self-propelled wagons of increased carrying capacity [9, 10, 15].

Combines "Ural-20R" carry out tunneling workings with a cross section of arched form. The number of moves in the practiced chamber is determined by the stability of the roof. The width of the interchamber pillars is taken from 1.5 to 7 m and depends on the width of the chamber, the thickness of the reservoir and the physico-mechanical properties of the ore being mined.

The completeness of extraction and loss of potassium-magnesium ores depends on the form of production. The amount of ore loss in the treatment chamber is calculated by the formula:

$$\Delta = \frac{S_{ra} - S_к}{S_{ra}} \cdot 100\ \%, \quad (2)$$

where $S_{ra}$ – the area of the rectangle described around the contour of the cross section of the mine worked by the combine, m$^2$; $S_к$ – cross-sectional area of the completed development, m$^2$.

When the thickness of the potash ore layer is more than 4 m, a two-layer mining of the chamber is applied with overlapping cross-sections in height, with the first stroke the tunneling machine excavates the upper layer (it works with full face). After distillation of the combine, the lower layer is worked out by the second move. At the same time, the face area is less than the cross-sectional area of the executive organs of the extraction machine – the combine harvester performs the undercut of the formation (Fig.1).

The destruction of the potash massif by the full cross section of the executive bodies is the most favorable condition for the operation of the "Ural-20R" combine, which ensures the maximum technical productivity of the excavating machine with the minimum specific energy consumption and dynamic loads on the drives [4, 6, 16].

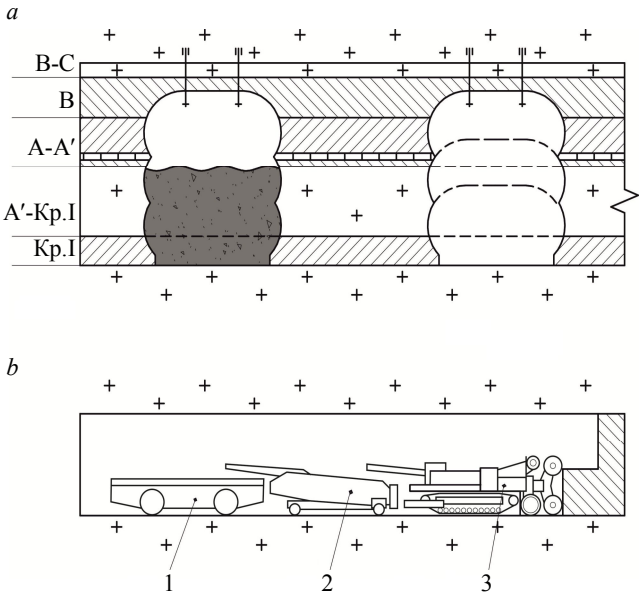



Fig.1. The undercut of productive layer with an incomplete section of the executive organs of the combine:
*a* – cross sections of production;
*b* – longitudinal section of the mine
1 – mine self-propelled wagon; 2 – hopper reloader; 3 – "Ural-20R" combine

DOI: 10.31897/PMI.2020.2.234

The technological operation of the tunneling is characterized by significant dynamic loads on the drives of the executive bodies of "Ural-20R" sinking and harvesting combines. The lack of effective damping devices and the pulsating nature of the loads determine the occurrence of impacts transmitted to shafts, bearings, gears, which leads to accelerated wear and emergency destruction of expensive gearboxes, and downtime of mining machines.

According to the reviews of service specialists, whose field of activity includes tasks related to the repair of "Ural-20R" combines, the majority of emergency failures of drive electric motors and gearboxes occur during operation of the combines with an incomplete section of executive bodies. Examples of the most frequent emergency failures of gearboxes of "Ural-20R" combines:

| Gear Name | Failure rate, % |
|---|---|
| Rotary planetary actuator | 35.6 |
| Berm executive body | 14.6 |
| Low-speed conveyor | 14.5 |
| Planetary Executive | 9.7 |
| Tracked undercarriage | 8.7 |
| High speed conveyor belt | 5.7 |
| The relative rotation of the planetary actuator | 3.8 |
| Fender device | 2.9 |
| Oil stations | 2.6 |
| Wearable rotation of a planetary actuator | 1.9 |

The standard control system of the Ural-20R combine is equipped with indicators of current loads of drive electric motors, the ultimate loads are monitored by "KORD" devices. When the induction motor overturns, a prolonged start-up (more than 2 s) or during technological overloads (more than 10 s), the device is activated and opens the power supply circuit of the corresponding motor with its contact [3, 4].

It should be specially noted that the standard electro-hydraulic control and indication systems of the "Ural-20R" combines do not allow controlling the magnitude of the dynamic component loads on the drives of mining machines.

In order to identify the basic laws of the process of forming loads on the drive elements of "Ural-20R" tunneling machines while working the face with an incomplete section of the executive bodies, the authors performed experimental studies in real operating conditions of these mining machines.

**Methods of experimental research.** Employees of the Department of Mining Electromechanics of the Perm National Research Polytechnic University developed and manufactured the "Vatur" software-recording complex, which provides measurement, recording and preservation of electrical parameters of the drive motors of "Ural-20R" tunneling and treatment combines (Fig.2.). The "Vatur" complex also includes an encoder-sensor, which makes it possible to record the values of movement and the feed rate of the combine to the face [6, 14].

"Vatur" registers the operation parameters of the drive motors of the "Ural-20R" combine for two voltage inputs. At each input (feeder), the loads of energy consumers are recorded, which can be either individual electric motors or a group of several consumers. To measure active power in a three-phase alternating current circuit, the method of one wattmeter with an artificial zero is used. The connection diagram of the current and voltage sensors on the Ural-20R tunneling machine is shown in Fig.3.

The instrument measures 5 kHz, i.e. during one period of voltage fluctuation of the supply network, 100 measurements are implemented. The primary processing of instantaneous values of currents and voltages, as well as the calculation of the effective values of these values, are carried out by the software of the computing unit directly during the experiment. In the process of primary data processing, the following parameters are determined.

The effective value of the phase voltage for each feeder (cable entry) is calculated by the formula:

$$U_{ef} = \sqrt{\frac{1}{n}\sum_{k=1}^{n} U_k^2}, \quad (3)$$

DOI: 10.31897/PMI.2020.2.234

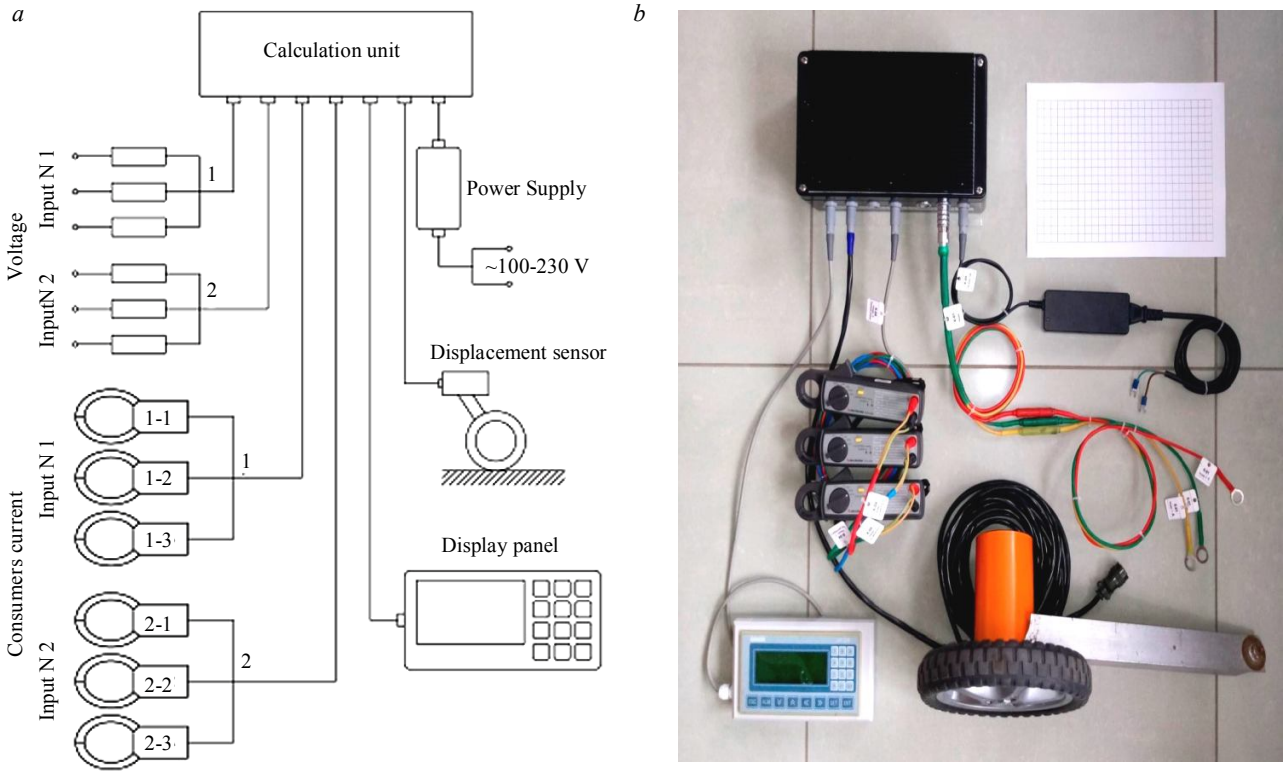



Fig.2. The software-recording complex "Vatur": *a* – block diagram; *b* – general view

where $U_k$ – the instantaneous value of the phase voltage measured by the device at the *k*-th moment of time, *V*; *n* – the number of measurement points for a fixed time interval $\Delta t$, during the experiments $\Delta t = 0.02$ s, $n = 100$.

The effective current value (for each current sensor) is calculated by the formula:

$$I_{ef} = \sqrt{\frac{1}{n}\sum_{k=1}^{n} I_k^2}\ , \tag{4}$$

where $I_k$ – instantaneous value of current at the *k*-th point in time, A.

The total and active power of the drive electric motors of the combine are determined by the formulas:

$$S = 3I_{ef}U_{ef}; \tag{5}$$

$$N_a = \frac{3}{n}\sum_{k=1}^{n} U_k I_k\ , \tag{6}$$

where *S* – total power of the corresponding drive electric motor of the "Ural-20R" combine, kVA; $N_a$ – active power of the drive motor of the combine, kW.

Power factor

$$\cos\varphi = \frac{N_a}{S}\ . \tag{7}$$

Combine feed rate

$$V_r = \frac{\sum_{k-1}^{n}(l_k - l_{k-1})}{\Delta t}\ , \tag{8}$$

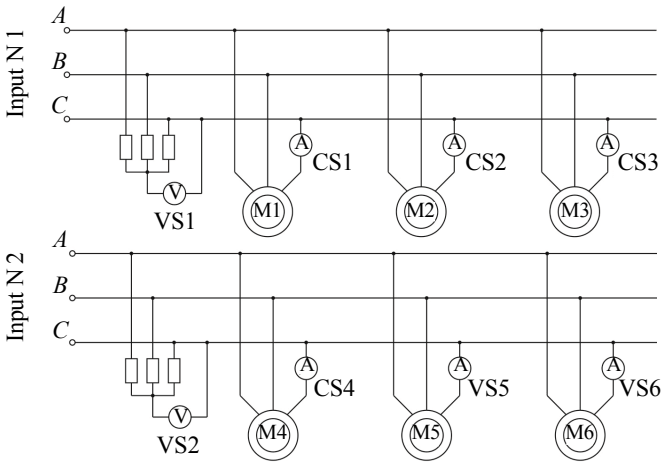



Fig.3. Scheme for measuring electrical parameters complex "Vatur": CS – current sensor; VS – voltage sensor




Fig.4. The working window of the "PC-Watur" program

where $l_k$ and $l_{k-1}$ – the position of the harvester at the current time k and the preceding time $k-1$, respectively, m.

The calculated values are stored in non-volatile memory of the software-recording complex. Further processing and analysis of the data array is carried out on a personal computer using the specially developed software "PC-Vatur". In the "PC-Watur" software environment (Fig.4), the data array of each measurement is visualized as a set of graphs on one-time axis. In the process of data processing, the researcher selects the boundaries of the analyzed sections of the graphs by setting the start and end measurement marks on the time axis. In order to determine the operating parameters of the "Ural-20R" tunneling machine in steady state, the corresponding measuring section is selected without transitional modes.

Evaluation of the variability of the loads on the drive elements of the executive bodies of the "Ural-20R" tunneling combines was carried out by determining the variance, mean square deviation and coefficient of variation of the active powers of the engines of mining machines [1, 6, 9].

**The procedure and results of experimental studies.** Investigations of the operation of the Ural-20R combine with an incomplete section of the executive bodies were carried out when the productive layer of the "Krasnyi II" layer was cut in one of the mines of the Verkhne-Kama deposit of potassium and magnesium salts. According to the data provided by the mine surveying service of the mine, the height of the massif to be destroyed was 1.0-1.1 m, the face area was 5.5-6.1 $m^2$, the angle of inclination of the mine varied in the range + 1-3° (the movement of the combine from the bottom up) .

In the course of the measurements, the "Ural-20R" tunneling combines worked with feed speeds close to those established by the operators in practice when performing such operations. The average feed rate of the combine was 0.40 m/min. The operator limited the feed rate of the excavating machine, focusing on the readings of the current indicators of loading drive electric motors. Based on the measurement data, we plotted the active power graphs of the electric motors of the Ural-20R tunneling combines (Fig.5).

The average values of the active powers of the drives of the surveyed combine were calculated, the mean square deviations and the coefficients of variation of the signals of the active powers were determined (see table).

DOI: 10.31897/PMI.2020.2.234

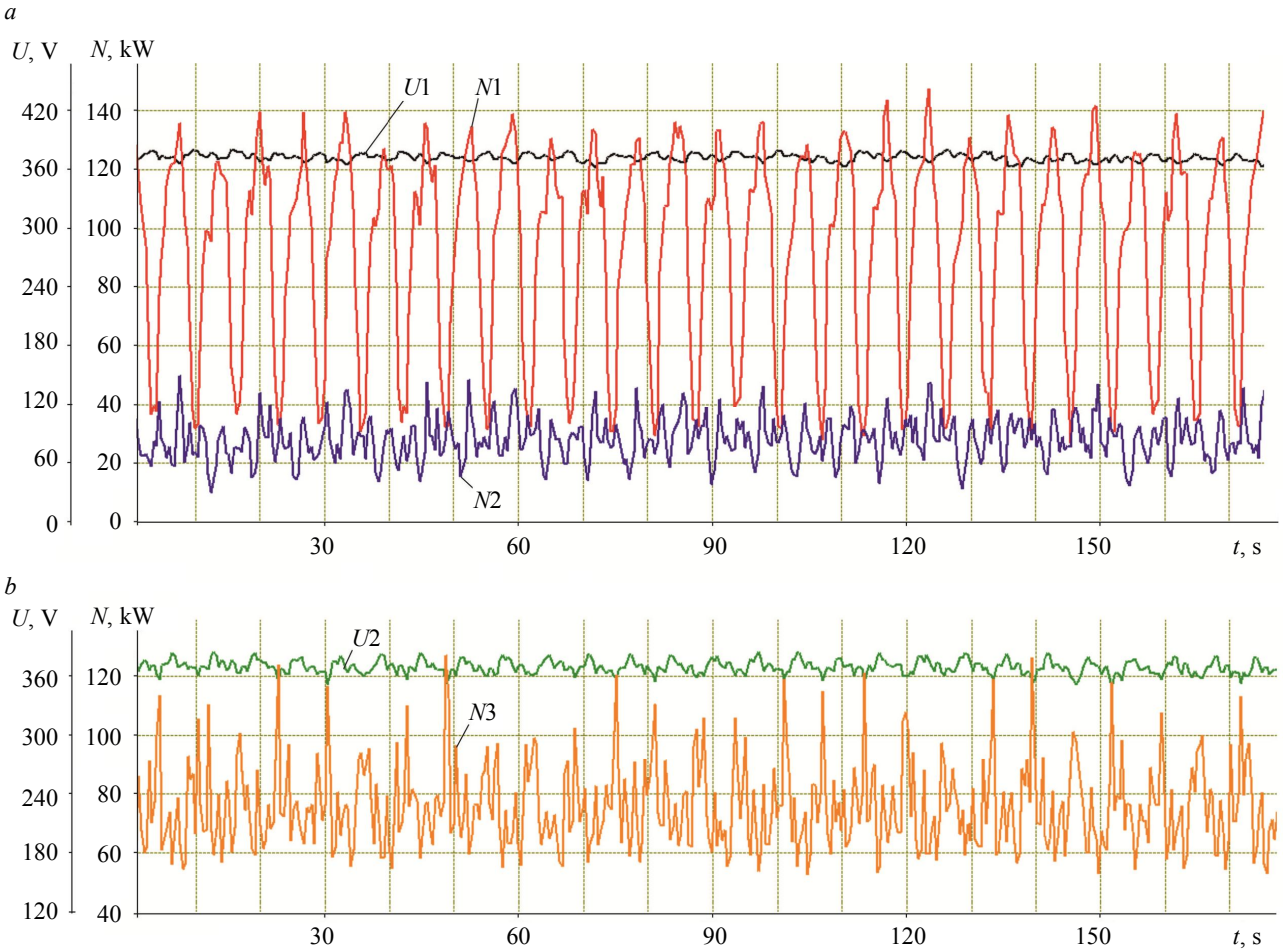



Fig.5. Changing the energy parameters of the drive motors of the "Ural-20R" tunneling machine while processing the bottom face with an incomplete section of the executive bodies ($Vr$ = 0.40 m / min): *a* – $U1$ – phase voltage at the input (feeder) N 1, $V$; $N1$ – active engine power of the relative rotation of the cutting discs, kW; $N2$ – active engine power of portable rotation of the planetary actuator, kW; *b* – $U2$ – phase voltage at the input (feeder) N 2, V; $N3$ – active power of the berm mill engine, kW

**The average values of the active power of the "Ural-20R" combine motors when processing the face with an incomplete cross-section (V*r* = 0.40 m / min)**

| Inspected drives | Average active power $N_a$, kW | Root mean square deviation $\sigma_N$, kW | Coefficient of variation $K_v$ | Active power at rated engine load, kW |
|---|---|---|---|---|
| Relative rotation 1 | 97.17 | 38.16 | 0.39 | 170.2 |
| Relative rotation 2 | 104.70 | 45.56 | 0.44 | 170.2 |
| Moving rotation | 36.20 | 7.57 | 0.21 | 81.5 |
| Berm organ | 169.73 | 17.56 | 0.20 | 163.0 |

The most loaded engines of the "Ural-20R" tunneling machine are the engines of the Berm executive bodies, which destroy the potash mass near the excavation soil and load the broken rock mass onto the scraper conveyor. The active power of the engines of the Berm organs exceeds the nominal value, while the variability of the loads is the lowest among the examined drives. This is due to the filling of the loading augers driven by the same electric motors as the berm cutters of the combine. Most of the power consumed by the engines of the Berm executive bodies is spent not on the destruction of the face, but on loading, circulation and overgrinding of ore in the spiral channels of the augers.

The most significant load variability is observed on the drives of the portable and relative motion of the incisal discs of the twin planetary actuators. When performing cutting of a productive formation, the mean square deviations of the capacities of these drives increase by 2.3-2.5 times in comparison with the mining of the bottom by a solid section.

DOI: 10.31897/PMI.2020.2.234

It should be especially noted that during the operation of the "Ural-20R" combine in the conditions under consideration in contact with the face, only one of the two rotary gearboxes of the planetary actuator is alternately located. Thus, the standard display system of the combine signals the presence of excess loads during double overload of rotary gear. This explains the fact that over 35 % of the total number of emergency failures of gearboxes of combines "Ural-20R" is accounted for by rotary gearboxes of planetary executive bodies.

The analysis of the research results showed that the feed rate of the combine harvester $V_r$ exceeded the permissible value by the criterion of the maximum permissible chip thickness $h_{max}$, the value of which is determined by the design of the rock cutting tool and the planetary executive body. The destruction of the potash mass by the planetary executive bodies of the Ural-20R tunneling machine with a feed speed of $V_r > 0.25$ m/min allows contact with the face of the fist tool holders. During visual observations of the movement of the "Ural-20R" combine during the cutting of a productive formation, significant vibrations of the body of the extraction machine, the mass of which is 110 tons, as well as slippage of the tracks of the running equipment, were noted [6].

**Conclusion.** The results of experimental studies presented in the article and the analysis of the statistics of emergency failures of "Ural-20R" tunneling combines allow us to draw the following conclusions.

When operating the "Ural-20R" combines with an incomplete cross-section of the executive bodies (carrying out the technological operation of cutting), the feed rate of the extraction machine to the bottom should be limited by the criterion of the maximum allowable chip thickness. The most loaded drives of "Ural-20R" combines are drives of berm executive bodies, since a substantial part of the energy in the process of their work is spent on moving and grinding potash ore. The loads of the drives of the relative movement of the incisor discs of the planetary actuators are characterized by the greatest variability, which determines the high probability of emergency failures of these drives.

The regular control and display systems of the "Ural-20R" combine need to be improved, since they do not allow controlling the dynamic load components of the combine drives and registering the feed rate of the combine to the face in real time.

The operation of the "Ural-20R" combine with an incomplete section of the executive bodies with a high feed rate leads to accelerated resource consumption and emergency failures of gearboxes and drive motors of the extraction machine.

## REFERENCES

1. Ivanov S.L. Increasing the transmission resource of mining machines based on the assessment of the energy load of their elements / Sankt-Peterburgskii gornyi in-t. St. Petersburg. 1999, p. 92 (in Russian).

2. Maksimov A.B. Improving the efficiency of the process of destruction of the potash array by planetary-disk executive bodies of production and treatment combines of the Ural-20R type. *Problemy razrabotki uglevodorodnykh i rudnykh poleznykh iskopaemykh*. 2018. N 1, p. 418-421 (in Russian).

3. Semenov V.V., Malcher M.A., Petrov V.P., Morozov S.P. Ural tunneling combines for the extraction of potash ore and rock salt. *Gornoe oborudovanie i elektromekhanika*. 2008. N 8, p. 17-21 (in Russian).

4. Starkov L.I., Zemskov A.N., Kondrashev P.I. The development of mechanized mining of potash ores. Perm: PGTU, 2007, p. 522 (in Russian).

5. Stebnev A.V., Gabov V.V., Korolev I.A. The analysis of stability and operating modes of the treatment mechanized complex. *Gornoe oborudovanie i elektromekhanika*. 2018. N 1, p. 37-40 (in Russian).

6. Trifanov M.G. Load assessment of drives of Ural-20R tunneling combine for the selection of technically sound operating modes in real operating conditions: Avtoref. Dis. … kand. tekhn. Nauk. Uralskii gosudarstvennyi gornyi universitet. Ekaterinburg, 2019, p. 20 (in Russian).

7. Koptev V.Yu., Kopteva A.V. Structure of energy consumption and improving open-pit dump truck efficiency. IOP conference series: earth and environmental science. 2017. Vol. 87. Iss. 7. N 022010. DOI: 10.1088/1755-1315/87/2/022010

8. Kuskova Ya.V., Lipnitsky N.A. Complex approach to the development of potash, potassium-magnesium and salt deposits. E3S WEB of conferences, IIIrd international innovative mining symposium. 2018. Vol. 41. N 01005. DOI: 10.1051/e3sconf/20184101005.

9. Kuvshinkin S.U., Zvonarev I.E., Ivanova P.V. Relationship of dynamic properties of mine excavator hoisting mechanism versus design parameters of operating equipment. *Journal of physics: conference series*. 2018. Vol. 1118. Iss. 1. N 012054. DOI: 10.1088/1742-6596/1118/1/012054

10. Lavrenko S.A., Korolev I.A. Analysis of Cambrian clay cutting during Saint Petersburg subway construction. *Gornyi Zhurnal*. 2018. N 2, p. 53-58. DOI: 10.17580/gzh.2018.02.08

11. Malarev V.I., Kopteva A.V., Koptev V.Yu. Electric power supply system development for down-hole electric steam generators to produce high-viscosity oil. 2018 international multi-conference on industrial engineering and modern technologies, FarEastCon. 2018. DOI: 10.1109/FarEastCon.2018.8602954

12. Mikhaylov A.V., Rodionov E.A., Zvonarev I.E. Analysis of conditions for vertical cutting of peat. *Mining informational and analytical bulletin*. 2019. Vol. 1, p. 48-54. DOI: 10.25018/0236-1493-2019-01-0-48-54

13. Sankovsky A.A., Aleksenko A.G., Nikiforov A.V. Practical experience analysis: superimposed seams series mining at the Verkhnekamsk potassium-magnesium salts depositap plyingroom-and-pillarmining method. *International journal of civil engineering and technology*. 2018. Vol. 9. N 6, p. 715-728.

14. Shishlyannikov D.I., Vasilyeva M.A. Research of the mine shuttle car drive mode at potash mines. Procedia engineering: 2nd international conference on industrial engineering, ICIE 2016. 2016. Vol. 150, p. 39-44. DOI: 10.1016/j.proeng. 2016.06.712

15. Trufanova I.S., Lavrenko S.A. Elaboration of the mathematical model of the intermediate linear drive belt with pressure rollers. *ARPN journal of engineering and applied sciences*. 2016. Vol. 11. N 19, p. 11581-11583.

16. Trufanova I.S., Lavrenko S.A. The efficiency improvement of belt c intermediate drive traction effort. *ARPN journal of engineering and applied sciences*. 2016. Vol. 11. N 7, p. 4317-4321.

17. Zvonarev I.E., Ivanov S.L. Evaluation of losses in transmission of machinery for development of mineral deposits in conditions of variable load. International conference on innovations and prospects of development of mining machinery and electrical engineering 2017, IPDME 2017. 2017. Vol. 87. N 2. N 022024. DOI: 10.1088/1755-1315/87/2/022024

18. Zvonarev I.E., Shishlyannikov D.I., Maksimov A.B. Efficiency increase of process of loading of potash ore while working with heading and winning machine "Ural-20R". *Journal of physics: conference series*. 2018. Vol. 1118. Iss. 1. N 012053. DOI: 10.1088/1742-6596/1118/1/012053

***Authors*: Dmitriy I. Shishlyannikov,** *Candidate of Engineering Sciences*, *Associate Professor*, *dish844@gmail.com* (*Perm National Research Polytechnic University*, *Perm*, *Russia*), **Mikhail G. Trifanov,** *Candidate of Engineering Sciences*, *Researcher*, *mec@pstu.ru* (*Perm National Research Polytechnic University*, *Perm*, *Russia*), **Gennadiy D. Trifanov,** *Doctor of Engineering Sciences*, *Head of Department*, *kanat@pstu.ru* (*Perm National Research Polytechnic University*, *Perm*, *Russia*).

*The paper was received on 22 July, 2019.*
*The paper was accepted for publication on 26 January, 2020.*