Efficiency improvement of loading of potassium ore by means of «Ural-20R» heading-and-winning machine

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Abstract. The paper deals with certain operation features of «Ural-20R» heading-and-winning machines. It has been proven that the efficient capacity field of such excavation machines is limited by the capacity of the subsequent loading equipment: a worm conveyor and a drag-bar reclaim conveyor. The crushing of potassium rock mass by chisels of the operation devices of «Ural-20R» machines is accompanied by intensive circulation and excessive ore degradation during transportation of the rock mass by single cut worms. Intermittent feeding of the ore to the conveyor stipulates considerable framework vibrations and formation of dynamic loads on the elements of the power drive of the reclaim conveyor. When the winning machine is used in mines with negative inclination angles, the capacity of the drag bar reclaim conveyor is drastically reduced. Based on the analysis of structural features of the worms and the conveyor of «Ural-20R», technical proposals have been made as to the efficiency improvement of potassium ore loading.

1. Introduction
For the time being, the most popular heading-and-winning machines in the RF are machines of «Ural-20R» type, the field of their efficient operation and their technical capacity are limited by the capacity of their worm conveyors and drag-bar reclaim conveyors. The improvement of the design of their assemblies is a vital goal.

2. General information about loading equipment
The loading equipment of «Ural-20R» is of skid type, comprising two one-cut worms with non-rotatable chisels on the blades, and a drag-bar reclaim conveyor. The worms ensure simultaneous hewing of the ore (cleaning-up) and feeding of the rock mass to the conveyor for loading of potassium ore to a re-loading hopper or a motor carriage.

The worms of «Ural-20R» are mounted on a common shaft; they are mechanically connected to the bankette operation device. The torque is transmitted to the bankettes and worms via mechanical gear reducers from two asynchronous motors of 150 kW joint power output. Based on calculations and experimental investigation results, it was found out that hewing the ore by the chisels of the worm crushers and berm mills requires a power of maximum 70 kW [1-4]. Consequently, the main power share is consumed for loading operations making considerable resistances evident during moving of the ore hewn. The most unfavourable rock mass loading conditions occur during machine operation in
mines with negative inclination angles (downward motion). By gravity, the ore hewn rolls down to the face space, re-circulates between the worm blades and the face, getting intensively degraded.

Single-cut worms of «Ural-20R» machines ensure intermittent feeding of the ore to the conveyor in portions causing considerable framework vibrations during the operation of the drag-bar reclaim conveyor and generating dynamic load components on the gear reducer and the drive motor of the conveyor. The uneven distribution of the rock mass along the worm is stipulated by the quantity increase of the delivered rock mass along the worm length to the discharge worm end, as well as by the thrust effect of the blade pushing the material portion (Figure 1).

3. Evaluation of loading efficiency
In case all the load is driven in axial direction, the supply capacity of the worm equals

\[ Q_s = \frac{\pi}{4} \left( D_L^2 - D_C^2 \right) \cdot \omega \cdot K_W \cdot \left( S - \frac{\delta \cdot N_W}{\cos \beta} \right) \cdot \gamma, \]  

with worm supply capacity \( Q_s \), t/min; worm blade diameter \( D_L \), m; worm hub diameter \( D_C \), m; RPM number of the worm rotation \( \omega \); filling factor of the worm \( K_W \); worm pitch \( S \), m; cuts number of the worm \( N_W \); worm blade thickness \( \delta \), m; worm blade lead angle \( \beta \); potassium ore bulk density \( \gamma \), t/m³.

The equation (1) makes it clear, that the loading capacity is mostly determined by the diameter values of the blade and the hub of the worm device, that is, the exact proportion of \( DL/DC \). For worms of «Ural-20R» machines, the proportion is \( DL/DC = 1.7 \). It is a proven fact that the design of worms for rock mass loading should envisage \( DL/DC > 2.5 \).

Of minor significance for the driving capacity of the worm is the number of cuts of the work blade. Experimental results show that the influence of the number of cuts \( N_3 \) on the capacity \( Q_S \) is mainly displayed at small filling factor values \( K_W \), whereas during considerable filling of the worm, the value \( \delta N_3/\cos \beta \) can be neglected [5].

The arrangement of chisels on the blades of single-cut worms implements sequential potassium ore mass degrading (Figure 1a) with thin cuts. As a result, the specific energy consumption for the ore extraction is 5-6 fold higher than that of the chisels of planetary disk operation devices [6-7].

Figure 1. Rock mass transportation schedule and chisels arrangement on worm blades: a) single-cut worm; b) double-cut worm
The framework of the drag-bar conveyor of «Ural-20R» has an 18º inclination to the caterpillar propulsion platform. According to the technical documents of the manufacturer, such excavation machines may be operated in mines with inclination angles within ±12º. Accordingly, the inclination angle of the conveyor to the horizontal plane $\alpha$ can be up to 30º (Figure 2).

The angle of repose of potassium ore, separated from the rock mass, at rest, is 35…40º. When the machine is operated with significant vibrations of the conveyor framework and uneven chain motion, the repose angle $\rho$ of the ore driven along the chute is 20…25º [8]. Depending on the framework inclination angle of the reclaim conveyor to the horizontal plane, the conveyor capacity can be determined as follows:

$$Q_C = 60 \cdot \gamma \cdot v_C \cdot l_B \left( h_B + \frac{\sin(\rho + \alpha) \cdot \sin(\rho - \alpha)}{2 \sin 2 \rho} \cdot t_B \right);$$

with conveyor framework inclination angle $\alpha$, degrees; repose angle $\rho$ of potassium ore driven along the chute of the drag-bar conveyor, degrees; theoretical conveyor capacity $Q_C$, t/min; conveyor chain speed $v_C$, m/s; drag bar length $l_B$, m; drag bar height $h_B$, m; $t_B$ – drag bar pitch, m.

For calculation purposes let us set $\rho=22^\circ$. Then, the condition $\alpha<\rho$ is complied with during the machine propulsion upwards along the mine with up to 12º inclination and downwards along the mine with down to –4º inclination (Figure 2 a). In the aforesaid application of the machine, in accordance with the equation (2), the conveyor capacity is increasing proportionally to the chain speed increase and the drag-bar dimensions. A decreasing of the drag-bar pitch reduces the capacity of the reclaim conveyor.

The downward mine inclination increase from –4 down to –12º ($\alpha\geq\rho$) will bring a rapid conveyor capacity decrease. The bulk volume between the drag-bars of the reclaim conveyor of the HWM is reduced (Figure 2 b). In accordance with the equation (3), a smaller pitch of the drag-bars enables an increase of the conveyor capacity. The diagram conveyor capacity fluctuations vs. mine inclination angle can be seen in figure 3.

The diagram $I$ has been set up in accordance with the specifications of the drag-bar reclaim conveyor of «Ural-20R» HWM: $v_C=1.24$ m/s; $l_B=0.72$ m; $h_B=0.087$ m; $t_B=0.516$ m; $\gamma=1.3$ t/m³; $\rho=22^\circ$. The diagram drawn demonstrates that the calculated theoretical conveyor capacity value is higher than the one stated in the technical documents on «Ural-20R», at the inclination angle of the conveyor framework to the horizontal plane $\alpha<18^\circ$. At $\alpha=30^\circ$, the conveyor capacity value $Q_C$ makes up 3.4 t/min, that is, less than half the datasheet capacity value of the excavation machine.
Figure 3. Capacity fluctuation diagrams of the drag-bar reclaim conveyor of the excavation machine depending on mine inclination: 1 – conveyor of «Ural-20R» HWM; 2 – drag-bar pitch 1.5-fold less; 3 – drag-bar height increased by half

A capacity increase of the drag-bar reclaim conveyor and the worms of «Ural-20R» is possible by means of the following technical solutions.

The design proportion of the worm dimensions $D_l/D_s > 2.5$ enables an increase of the specific transportation capacity, an installation of double-cut worms will ensure a smoother ore loading from the face space to the drag-bar conveyor, thus considerably reducing vibrations and dynamic loads on the power drives of the equipment of «Ural-20R». The use of double-cut worms (Figure 1 b) will implement the chequerwise rock mass crushing by the chisels mounted on the worm blades. The results of experiments conducted by the authors demonstrate that in case of chequerwise cuts of 5 mm depth, as compared with serial cuts of the same depth, the specific power consumption goes back from 6 down to 3.2 kWh/m$^3$, the output of small ore grades gets back from 6,5 down to 5 % [9-10].

The reduction of the pitch (diagram 2, figure 3) and increasing of the drag bar height (diagram 3, figure 3) by a half, as compared with the conveyor of «Ural-20R», will allow for an increase of the minimum calculated capacity of the drag-bar reclaim conveyor 1.5 and 2.25 times, respectively. The modernization of the conveyor will, along with the technical capacity increase, allow for the reduction of the quantity of small ore grades and for the reduction of the specific power consumption for loading of the rock mass due to lessening the material recirculation and repeated degrading ore combine screws.

4. Conclusion
For more efficient use of «Ural-20R» heading-and-winning machines, cleaning-up and preparation works must be planned in such a way that the developed mines have zero or positive inclination.

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