Efficiency increase of process of loading of potash ore while working with heading and winning machine ‘Ural-20R’

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Abstract. Some operating characteristics of heading-and-winning machines ‘Ural-20R’ were subject to investigation. It was proved that the scope of effective application of these winning machines is restricted by the capacity of the loading operating equipment: screw conveyors and chain-and-flight conveyors. The potash solid destruction by means of the business end of ‘Ural-20R’ machines is supplemented by intense ore circulation and over-degradation when transported using single-thread screw conveyors. Feeding of ore in discrete quantities to the conveyor causes significant base plate vibrations and formation of dynamic loads on drive elements of chain-and-flight conveyors. When using winning machines in workings at a negative inclination angle, flight-and-chain conveyors capacity decreases significantly. Technical proposals on the improvement of potash ore loading process efficiency were developed based on the analysis of specific design properties of screw conveyors and ‘Ural-20R’ combined machine conveyors.

1. Introduction
At present heading-and-winning machines ‘Ural-20R’ are widely used at potash mines of the Russian Federation; the scope of effective application and technical efficiency of heading-and-winning machines is restricted by screw loaders and chain-and-flight conveyors capacity. Improvement of these units design is a critical task.

2. General information about loading equipment
The loading equipment of ‘Ural-20R’ combined machine is mounted on the common base plate and includes two single-thread screw conveyors that contain non-rotatable cutters on their blades and a chain-and-flight conveyor. Screw conveyors provide simultaneous ore breaking-down (sole cleaning-up) and rock mass transfer to the conveyor that is designed for loading of potash ore into the conveyor-hopper or a shuttle car.

The screw conveyors of ‘Ural-20R’ combined machines are mounted on the common base plate and are kinematically connected to berm tools. The torque is transmitted to berms and screw conveyors by means of mechanical transmissions from two asynchronous electrical motors with the total power of 150 kW. Based on calculations and research studies, it was established that ore breaking-down using screw conveyors and berm cutters require the power value not exceeding 70 kW. Therefore, the main portion of energy is used for loading that implies the presence of significant resistance during broken
ore handling. The most unfavourable conditions for rock mass loading are developed when combined machines are operated at workings at a negative inclination angle (downwards motion). Under the influence of gravity forces, the broken ore gets down to the bottom-hole area where it is circulated between the blades of the screw conveyor and the bottom and is intensively milled.

The single-thread screw conveyors of ‘Ural-20R’ combined machines provide ore feeding to the conveyor by portions in discrete quantities, thus causing significant base plate vibrations when the chain-and-flight conveyor is in operation and resulting in the formation of load dynamic components of the reducing gear and conveyor drive motor. Uneven rock mass distribution along the screw conveyor is caused by the increase in the amount of ore to be charged in the direction of the screw conveyor unloading end as well as by the thrusting action of the conveyor flight, before which a moving pile of material to be conveyed is formed (figure 1).

![Figure 1. The scheme for rock mass transportation and cutters placement on screw blades: a – for single-thread screw conveyor; b – for double-lead screw conveyor.](image)

3. Evaluation of loading efficiency

The screw conveyor capacity in relation to the conveying capacity provided that the total mass transferred in the axial direction is equal to:

\[ Q_s = \frac{\pi}{4} \left( D_b^2 - D_h^2 \right) \omega K_{ch} \left( S - \delta N_s \cos \beta \right) \gamma \]

where \( Q_s \) – screw conveyor capacity in relation to the conveying capacity, t/min; \( D_b \) – screw conveyor blade diameter, m; \( D_h \) – screw hub diameter, m; \( \omega \) – screw rotation frequency, t/min; \( K_{ch} \) – screw conveyor charging factor; \( S \) – screw conveyor pitch, m; \( N_s \) – number of Archimedean screws; \( \delta \) – screw
blade thickness, m; \( \beta \) – screw blade elevation angle, degrees; \( \gamma \) – potash ore density in the stocking, t/m\(^3\).

It follows from the expression (1) that screw blades and hub diameters, to be more specific the ratio \( D_b/D_h \), put the greatest effect on the loading capacity. For ‘Ural-20R’ combined machines screws, the ratio is \( D_b/D_h = 1.7 \). It was proved that when designing screws performing rock mass loading operations, the ratio \( D_b/D_h > 2.5 \) shall be used.

The number of Archimedean screws has lesser influence on the screw conveying capacity. The results of research studies show that the effect of the number of Archimedean screws \( N_S \) on the capacity \( Q_S \) is more evident at small values of the screw conveyor charging factor \( K_{ch} \), while in case of significant screw charging, the value of \( \delta N_S/\cos\beta \) can be neglected.

Installation of cutters on single-thread screws blades determines the implementation of the sequential circuit of potash mass destruction (figure 1а) by small thickness cutting; thus the specific energy consumption for ore separation is 5-6 times higher than that during bottom destruction by means of cutters of planetary-disk elements of the combined machine.

The base plate of the chain-and-flight conveyor of ‘Ural-20R’ combined machine is mounted at the angle of 18º to the plane of a caterpillar carrier. According to the Manufacturer’s technical documentation, these winning machines can be used at bottoms with the inclination angle of ±12º. Therefore, the conveyor inclination angle in relation to the horizontal plane \( \alpha \) can be up to 30º (figure 2).

![Figure 2](image)

**Figure 2.** The design scheme of chain-and-flight conveyors of ‘Ural-20R’ combined machine: a) \( \alpha < \rho \); b) \( \alpha \geq \rho \).

The depositional gradient of the potash ore separated from the solid, being at rest, is equal to 35-40º. The operating combined machine causes significant vibrations of the conveyor base plate and results in chain uneven motion; and the depositional gradient of the ore conveyed along the trough \( \rho \) is 20-25º. Depending on the loader base plate inclination angle in relation to the horizontal plane, the conveyor capacity can be determined as follows:

\[
Q_T = \begin{cases} 
60\gamma v_{ch} l_f \left( h_f + \frac{\sin(\rho + \alpha)\sin(\rho - \alpha)}{2\sin 2\rho} t_f \right) & \text{if } \alpha < \rho; \\
60\gamma v_{ch} l_f \left( h_f - \frac{\tan(\rho - \alpha)}{2} t_f \right) & \text{if } \alpha \geq \rho;
\end{cases}
\]

where \( \alpha \) – conveyor base plate inclination angle in relation to the horizontal plane, degrees; \( \rho \) – the depositional gradient of the potash ore conveyed along the trough of the chain-and-flight conveyor, degrees; \( Q_T \) – conveyor estimated capacity, t/min; \( v_{ch} \) – conveyor chain travel rate, m/s; \( l_f \) – flight length, m; \( h_f \) – flight height, m; \( t_f \) – distance between flights, m.

When making calculations, we set the value of \( \rho = 22º \). Then the restraint of \( \alpha < \rho \) can be fulfilled...
when the combined machine moves upwards at workings at the inclination angle of up to 12° and when it moves downwards at workings at the inclination angle of up to −4° (see figure 2 a). Within the specified scope of combined machines application according to the expression (2), the conveyor capacity increases proportionally if the conveyor chain travel rate and flight dimensions are increased. The reduction of the distance between flights results in the decrease in the loader capacity.

The increase in the workings inclination angle from −4 to −12° (α ≥ ρ) results in the intense decrease of conveyor capacity. The amount of ore transported between the flights of the combined machine loader decreases significantly (see figure 2 b). According to the expression (3), the decrease of flights spacing pitch will allow increasing the conveyor capacity. The graphs of conveyor capacity change for different workings inclination angles are given in figure 3.

![Figure 3](image)

**Figure 3.** The graphs of capacity changes for winning machine chain-and-flight conveyor depending on the workings inclination angle: 1 – ‘Ural-20R’ combined machine conveyor; 2 – conveyor flights spacing pitch reduced 1.5 times; 3 – conveyor flight height increased 1.5 times.

Graph 1 is plotted in accordance with the technical specifications of the chain-and-flight conveyor for the ‘Ural-20R’ combined machine: \(v_{ch} = 1.24 \text{ m/s}; l_f = 0.72 \text{ m}; h_f = 0.087 \text{ m}; t_f = 0.516 \text{ m}; \gamma = 1.3 \text{ t/m}^3; \rho = 22°\). The graph plotted shows that conveyor theoretical design capacity exceeds the value of the capacity specified in the technical documentation for the combined machine ‘Ural-20R’ for the base plate inclination angle in relation to the horizontal plane of \(\alpha < 18°\). If \(\alpha = 30°\), the conveyor capacity value \(Q_T\) amounts to 3.4 t/min that is more than twice less than the rated capacity (specified in the nameplate) of the winning machine.

The chain-and-flight conveyor capacity and screw conveyors capacity of ‘Ural-20R’ combined machine can be increased by applying the following technical solutions.

If \(D_h/D_b > 2.5\) ratio is met, then screw conveyor conveying capacity can be increased while installation of double-lead screws will ensure a more even process of ore loading from the bottom-hole area on to the chain-and-flight conveyor that will significantly reduce vibrations and dynamic loads on drives of ‘Ural-20R’ combined machine loading equipment. Use of double-lead screws (see figure 1 b) will allow implementing the checkrow scheme for the solid destruction using the cutters mounted on their blades. The results of research studies carried out by the authors show that when destructing the solid using the checkrow cuts 5 mm deep in comparison with the sequential cuts of the same depth, the specific energy consumption decreases from 6 to 3.2 kW·h/m³ and the fines yield reduces from 6.5 to 5%.

The decrease of flights spacing pitch (see graph 2, figure 3) and the 1.5-time increase of flights height (see graph 3, figure 3) compared to the ‘Ural-20R’ combined machine conveyor will allow increasing
the minimum design capacity of the chain-and-flight loader 1.5 and 2.25 times accordingly. The updating of the conveyor (in addition to its technical capacity improvement) will allow decreasing the fines yield and reducing the specific energy consumption required for the rock mass loading by means of reduction of ore circulation and re-breakage by combined machine screws.

4. Conclusion
In order to ensure a more effective use of the ‘Ural-20R’ heading-and-winning machines, it is necessary to plan first and second workings in such a way that the workings had zero or positive inclination angles.

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