Determination of rational parameters of auger loaders of «Ural-20R» heading-and-winning machines

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Abstract. The analysis of factors affecting the intensity of the process of grinding potash ore when loading by the auger body is performed. The main criteria for selection of rational parameters of auger loaders of heading-and-winning machines are indicated. The mathematical formulas are presented, including the design scheme of determining the rational value of the duty ratio of the cross-section of the screw, wherein minimal ore circulation providing in a screw spiral of the auger is developed. It is proved that work of auger loaders at rated performance of «Ural-20P-11/12» machines is accompanied by an increased filling ratio of interlobe space and ore circulation, which causes increase in the number of non-washable powdered classes in the breakage products. The dependence of the change of the rational fill factor and the productivity of the auger body on loading is established and analyzed. The rational value of a hub diameter of the auger loader of the «Ural-20P-11/12» machine in which minimum ore circulation and overgrinding in the spiral channels of the auger are determined by calculation. The technical solutions to improve the design of the augers are proposed.

1. Introduction

Extraction of potash ore by underground mining at enterprises of Russia and CIS countries is carried out using «Ural-20R» heading-and-winning machines produced by JSC «Kopeysk Machine-Building Plant». These machines are equipped with combined operating members of the drill type and caterpillar mounting [1, 2].

The executive bodies of «Ural-20R» machines combine in their work the processes of ore separation from massif with its loading from the workings ground onto the scraper reclaim conveyor, which performs removal of broken rock mass from the zone near face and further unload to accumulating containers or area transport means [3, 4]. As a loading and transportation in «Ural-20R» machines the augers providing the massif destruction (cleaning up the workings ground) and the rock mass movement to the loading window of the scraper conveyor are used [5, 6].

The work of modern modifications of «Ural-20R-11/12» machines at rated technical capacity Q = 8 t/min is characterized by an increased filling ratio of filling auger loaders with potash ore [7]. In the process of transportation and loading, a part of the ore is thrown through the auger hub, not moving in the axial direction. Circulation of the rock mass in the spiral channels of the auger and the area near face determines theragging of ore particles that is accompanied with increase of the number of small non-washable classes «0.25 mm» (particle size is less than 0.25 mm) in the breakage products [8]. Ore
grades «-0.25 mm» almost completely fall into waste [9]. The high content of dust-like particles makes it necessary to use sophisticated schemes for raw materials processing for preparation of dust-free potassium chloride, which increases the expenses of the mining enterprise [10].

An actual scientific and practical task is to reduce the ore circulation degree during handling and shipping of the near face area of augers of «Ural-20R» heading-and-winning machines. Reducing the degree of ore grinding makes it possible to reduce the expenses of mining enterprises and minimize the amount of waste of dressing works formation [11].

2. Method for determining the rational parameters of the auger loader of the «Ural-20R» machine

The rock mass moving with augers of the «Ural-20R» machine is a complex multifactorial process, which is characterized by substantial values variability of parameters affecting its performance. Reduction of potash ore grinding during loading is carried out under the condition that the productivity of the rock-destroying executive bodies of the machines is not limited by productivity of auger loaders. Otherwise there is a substantial increase of filling degree and ore circulation between the blades of the augers [12].

Productivity of the auger loading body is determined by the formulation [13, 14]:

\[
Q_{aug} = \frac{\pi}{4} \left( D_{aug}^2 - d_{aug}^2 \right) \gamma m_{aug} n_{aug} K_z K_c \left( t_{aug} - \frac{\delta N_z}{\cos \psi} \right) \tag{1}
\]

where \(Q_{aug}\) – auger technical capacity by loading, t/min; \(D_{aug}\) – auger diameter by blade, m; \(d_{aug}\) – auger hub diameter, m; \(\psi_{aug}\) – helix angle of auger, deg; \(t_{aug}\) – auger blade pitch, m; \(\delta\) – thickness of the auger blade, m; \(N_z\) – number of Archimedean screw of auger blades, pcs; \(m_{aug}\) – number of augers, pcs; \(n_{aug}\) – frequency of auger rotation, rev/min; \(\gamma\) – bulk density of potash ore, t/m³; \(K_z\) – fill factor of auger cross-section; \(K_c\) – coefficient of ore circulation from ore in the auger.

Determination of the rational value of auger fill factor \(K_{f, rat}\) is performed in accordance with the design diagram of the auger cross-section shown in Figure 1 [15]. The auger filling coefficient may be defined as a ratio of the area filled portion of the screw section to the total cross-sectional area of the screw interlobe space and is calculated by the formula:

\[
K_{f, rat} = \frac{F_{f, p}}{F_{n, ch} + F_{f, p}} \tag{2}
\]

where \(F_{f, p}\) – area of filled part of the auger cross section, m²; \(F_{n, ch}\) – area of not filled part of the auger cross section, m².

![Figure 1. Design diagram of the auger cross-section of the screw adopted to determine the rational fill factor \(K_{f, rat}\).](image-url)
The area of the filled part of the auger \( F_{\text{ch}} \) is determined taking into account angle \( \beta \), presented on the calculation scheme. Angle \( \beta \) defines the boundary above which the ore arrives onto the flattened surface of the auger hub and does not move in the axial direction, but is thrown through the hub.

The angle \( \beta \) depends on geometric and kinematic parameters of the auger screw loader, friction coefficient of ore with the auger surface and is defined by the following equation:

\[
\frac{gsin\lambda + fR_{\text{aug}}}{gcos\lambda} = \frac{2\pi R_{\text{aug}}}{t_{\text{aug}}} \left( 1 - f \sqrt{ctg^2\gamma_{\text{aug}} + \left( \frac{t_{\text{aug}}}{2\pi R_{\text{aug}}} \right)^2 + 1 + fctg\gamma_{\text{aug}}} \right) \sin \beta - f \cos \beta \tag{3}
\]

where \( \beta \) is the potash ore entrainment angle by the hub auger into the tangent motion, degrees; \( g \) – gravitational acceleration, m/s\(^2\); \( \lambda \) – angle of inclination of the auger axis to the horizontal plane, degrees; \( f \) – friction coefficient of potash ore by metal; \( R_{\text{aug}} \) – auger radius along the blade, m; \( \gamma_{\text{aug}} \) – inclination angle of auger blade generatrix relative to the auger rotation axis, degrees.

The rational value of the fill factor of the screw \( K_{f\text{rat}} \), determined when solving equations (2) and (3), corresponds to the minimum value of the ore circulation coefficient in auger spiral channels \( K \). Increase of the auger fill factor above the region of rational values \( (K_f > K_{f\text{rat}}) \) causes increase in the ore circulation degree in it [16].

Performance of the auger loader of the «Ural-20R-11/12» machine, determined by expressions (1)-(3) and corresponding to the minimal value of ore circulating between the blades, is \( Q = 7.5 \) t/min. With nominal performance of the «Ural-20R-11/12» machine of \( Q = 8 \) m/min the increased filling ratio of interlobe space of the augers and ore circulation in spiral channels of screw loader that stipulates the increase in the number of dust-like classes «0.25 mm» in the breakage products.

From the expression (1) it follows that at a constant value of the auger outer dimensions of the «Ural-20R» machine (blade diameter \( D_{\text{aug}} = 0.68 \) m) the greatest influence on its loading performance \( Q_{\text{aug}} \) has the hub diameter \( d_{\text{aug}} \), which rational value must be determined [17].

### 3. Determination of rational parameters of augers of «Ural-20R» machines

Determination of rational design parameters of augers of «Ural-20R» machines is performed based on the condition to ensure the heading-and-winning machines rated capacity with minimal ore circulation and breakage between the auger blades [18].

In order to determine the rational auger parameters corresponding to the smallest grinding of ore being displaced, the value of ore circulating factor in the auger is accepted as a minimum possible one, that is, \( K_C = 1 \).

The value of angle \( \beta \) for transportation of potash ore with the augers of the «Ural-20R-11/12» machine with the calculated filling scheme of the auger cross-section (see Figure 1) is determined from expression (3) and is equal to \( \beta = 35^\circ \). If \( \beta < 35^\circ \) ore is thrown through the hub of the screw, which causes an increase in intensity of circulation and grinding of ore particles being moved.

The authors of this work obtained by calculation the meanings of the fill factor rational value \( K_{f\text{rat}} \) when the received calculation scheme and defined angle \( \beta \) (\( D_{\text{aug}} = \text{const} \)) are in the range of auger hub diameter \( d_{\text{aug}} \) [0.1 m; 0.6 m]. Using the method of polynomial approximation the dependence of the fill factor \( K_{f\text{rat}} \) rational value change on auger hub diameter \( d_{\text{aug}} \) is obtained:

\[
K_{f\text{rat}} = -31.5d_{\text{aug}}^5 + 56.11d_{\text{aug}}^4 - 36.13d_{\text{aug}}^3 + 9.57d_{\text{aug}}^2 - 0.46d_{\text{aug}} + 0.5 \tag{4}
\]

Substituting the fill factor \( K_{f\text{rat}} \) defined by relation (4) into the expression (1), we obtain the dependence of the auger body performance \( Q_{\text{aug}} \) on the auger hub diameter \( d_{\text{aug}} \) presented in figure 2 [19, 20].
Based on the condition that the auger performance should not limit the machine performance, to determine the rational values of the hub diameter, we take $Q_{aug} \geq 8 \text{ t/min}$. Thus, it is necessary that the hub diameter belong to the values range $d \in [d_{min}; d_{max}]$ (see figure 2).

With the value $d = D/3$ there is an extremum of function $Q_{aug} = f(d)$, corresponding to maximal value of the auger productivity $Q_{aug} = 9.41 \text{ t/min}$.

Reducing the diameter of the auger hub less than $d < D/3$ entails reduction of auger productivity $Q_{aug}$, corresponding to the rational values of auger fill factor $K_{f.rat}$. In the values range of the auger hub diameter $d \in [d_{min}; D/3)$ the predetermined strength characteristics of «Ural-11/12-20R» machine augers are not assured.

Rational value of the auger hub diameter $d$ providing the smallest ore overgrinding during transportation for «Ural-20R-11/12» heading-and-winning machines is in the range of $d \in [D/3; d_{max}]$, which corresponds to the values of 0.23-0.37 m (diameter of the auger hub of the serial «Ural-20R-11/12» machine, $d = 0.4$ m).

The work of «Ural-20R» machines augers is characterized by absence of closed spaces in the circumferential direction. The gaps between the blades of the augers, face and guard shield are significant, causing circulation and ore leakages from action zone of loading blades, forming a spillage layer on the workings ground [21, 22].

To eliminate the aforementioned drawback replacement of the loading sharer of the machine having rounded shape (Figure 3), is proposed which makes it possible to reduce the amount of ore, moved outside the contour of the auger blades [23, 24].
A way to reduce the intensity of potash ore reduction during the work of the «Ural-20R» machine is to change the cutter holders position on the augers [25]. It is rational to place cams with cutters on the unwork side of the auger vane so that they do not protrude beyond the blade diameter. It should be noted that with this arrangement of cutter holders it is necessary to use cutters with increased radial overhang.

4. Conclusion

The loading equipment of heading-and-winning machines must be designed in such a way that the technical performance of the loaders exceeds the overall performance of concretion cutting operating members of the excavation machines. The design parameters of the loading bodies should be calculated from the condition providing minimal circulation of ore in the near face space.

The augers of the serial «Ural-20R-11/12» machine are characterized by high filling coefficient at the machine work with a nominal capacity of 8 t/min, which causes ore circulation and overgrinding under loading. Reducing ore grinding may be achieved by reducing the auger hub diameter from 0.4 m to 0.35-0.37 m. By calculation it is proved that the maximum auger capacity by loading capacity 9.41 t/min for a given blade diameter of 0.68 m is provided with a 0.23 m hub diameter.

Improving the loading efficiency and reduction of potash ore overgrinding by «Ural-20P» machine augers can be achieved by the cutter holders installation on the unwork side of the auger vane so that they do not protrude beyond the blade diameter.

Replacing the shield installed behind the auger loading body of the «Ural» machine onto the loading sharer of the machine having rounded shape makes it possible to reduce the amount of ore, moved outside the contour of the auger blades, reduce the circulation and grinding of the ore during loading.

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