Relocation schemes of picks with cutting, coupling and group cuts on shearer cutting drums

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Abstract. The possibilities of increasing the efficiency of separating coal from the massif by improving the pick alignment schemes of shearer cutting drums are considered. Given the existing structural limitations of the radial extension of the picks and the thickness of the cuts, an increase in efficiency is achieved by using combined series-group schemes for arranging picks, including energy-efficient cutting, paired and group with a larger cross-sectional area of the cuts and, therefore, with a larger particle size of the separated coal fragments, reduced dust yield and specific energy consumption.

1. Introduction

Narrow-cut combines with cutting drums are currently the most widely used in the processes of coal mining in complex mechanized working faces of coal mines. They are equipped with almost all manufacturing mechanization complexes used on formations of medium and high seam thickness with bedding angles of up to 35° [1].

It is known that the main advantages of auger screws are the possibility of self-cutting into the formation to a new excavation strip by oblique rides, the ease of regulation of the position of the screws according to the thickness of the formation, the combination of the functions of separating coal from the massif and loading it onto the conveyor, reliability and durability. In practice, the work of complex mechanized working faces on medium and high seam thickness and other alternatives is not expected for the near future [1].

However, according to the main efficiency criteria (Fig. 1), in the process of separating coal from the massif the auger screws have significant disadvantages: overgrinding of coal (W-d,%, more than 40% of small classes in the total mass of coal mined); relatively high specific energy consumption (Hw); increased dust formation and high costs of deposition, neutralization and cleaning of explosive and fire hazardous coal dust generated during cutting [2, 3]. With an increase in the intensity of the process of separating coal from the massif, these disadvantages are manifested even more significantly.

Therefore, the search for more effective ways of separating coal from the massif and the corresponding technical solutions that ensure the elimination or reduction of the influence of the above disadvantages in relation to auger screws are relevant.

2. Results and discussion.

Increasing the efficiency of the process of coal separation from the massif is most simply achieved by increasing the thickness of the slices and, consequently, the width and cross-sectional area of the
slices. However, the thickness of the cut is limited by the radial extension of the picks and the degree of fitting of their tool holders into the shotpile of the cuts.

The idea of increasing the efficiency of the cutting process is to use, along with sequential and staggered slices, more energy-efficient cutting, paired and group slices, as well as combined sequential-group schemes for arranging picks on the cutting drum.

Figure 1. Criteria and performance indicators of the process of separating coal from the massif by shearsers picks. $S_{cp}$ is the cross-sectional area of the slice, $m^2$; $v_p$ - cutting speed, $m/s$; $\gamma$ - the density of coal in the array, $t/m^3$; $P_{av}$ - power flow of energy, $kW$; $d$ - diameter of particles (pieces) of coal, $m$; $\lambda$ - the degree of grinding; $m$ - the shape parameter.

When cutting, paired and group cuts are carried out by adjacent picks, combined local critical stress regions are formed in the pick zones of the array. This ensures, under the existing restrictions on the radial departure of the picks, the separation of coal from the massif with slices of a larger width and cross-sectional area and, consequently, a decrease in the specific energy consumption and volumes of small classes of coal and dust generated during the cutting process.

Depending on the values of the thickness ($h$) and width ($t$) of the slices, their ratios, as well as the location of the exposed surfaces of the destroyed array, the cutting process will proceed under various conditions [5-9]. In the practice of equipping the cutting drum of shearsers with picks, the most common use is a sequential cut (Fig. 2, a) and a consistent arrangement of picks.

A sequential cut is characterized by the presence of two outcrop planes and is accompanied by a one-sided collapse of the cut groove. The surface of the face after the slices is not aligned. At the same time, the process of separating coal or rock from the massif is stable, with a low probability of oversized output, and it is recommended for the development of very strong, viscous and even especially strong coal seams. This type of cut is accepted as the initial (base) one for further comparison with the studied undercut, paired and group cuts and the corresponding patterns for arranging picks. The studied sections in the form of their sections, the conditions of the cut, and the presence of outcrop planes (Fig. 2) are similar to a sequential cut.

An undercut is formed when the incisor moves along a face of height $H$ with two exposure planes and the incisor axis tilts to the face at an angle $\gamma$ (Fig. 2b) close to 900, is accompanied by a one-sided collapse of the incision groove. The surface of the face after the slices is not aligned. The height of the face $H$ can be somewhat larger than the thickness of the sequential cut ($t_s$) (see Fig. A, b), and the specific energy consumption ($H_s$) is slightly less than the specific energy consumption for a sequential cut.

A paired slice (Fig. 2, c) is formed by two equally sized adjacent incisors installed without advancing and parallel to each other [10, 11]. Slice conditions are characterized by the presence of two
exposure surfaces. The slice is accompanied by a one-sided collapse of the slit groove; it is distinguished by the formation of a single critical undercutting stress zone in the massif, which causes larger elementary chips \[2, 12\] and a larger width of the pair slice groove \( (t_{np}) \):

\[
t_{np} = 2t_n k_{np}, \quad (1)
\]

where: \( t_n \) is the width of the sequential cut; \( k_{np} \) is the coefficient of the width of the pair cut, \( k_{np} = 0.8 \div 0.9 \).

A group cut (Fig. 2d) is formed by radial or tangential picks of the same size. Slice conditions are characterized by the presence of, as a rule, two exposure surfaces. The slice is accompanied by unilateral or bilateral collapse of the groove of the slice, depending on the arrangement of the picks on the cutting drum, and differs from the sequential and paired slices, with the same thickness, large width and cross-sectional area of the group slice. The group cut provides the output of larger fractions during coal mining, reducing the volume of dust output and specific energy consumption.

**Figure 2.** Sections of slices:
- (a) sequential; (b) cutting; (c) doubles; (d) group;
- \( S_n \) sectional area of a sequential cut; \( S_{nd} \) sectional area of the undercut;
- \( S_{np} \) sectional area of a pair cut; \( S_{on} \) is the cross-sectional area of the leading cut;
- \( S_{gp} \) is the cross-sectional area of the group slice; \( h_n \) is the thickness of the sequential cut; \( h_{nd} \) is the thickness of the undercut; \( h_{np} \) is the thickness of the pair cut; \( h_{gp} \) is the thickness of the group cut; \( t_p \) is the width of the sequential cut;
- \( t_{pd} \) undercut width; \( t_{np} \) is the width of the pair cut; \( t_{on} \) is the width of the leading cut; \( t_{gp} \) is the width of the group slice; \( b \) is the diameter of the pick.

The width of the group cut is \( (t_{gp}) \):

\[
t_{gp} = t_{on} + 2t_{nd} \quad (2)
\]

The group arrangement of incisors \[13\] on the screw actuator (Fig. 3, c) is known, the blades of which are equipped with groups of radial and tangential incisors in alternating planes of rotation. In each plane of rotation, at least two toolholders for groups of radial tools and no more than one pick box for tangential tools are installed. In this case, the pick box for the group of radial picks is made with three slots for fixing the picks 1, 2 and 3 (Fig. 3, a), one of which (3) is located ahead of the other.
two (1, 2), installed at an angle to the plane of rotation. The sequence of sections 5–10 and 11–16 formed in the process is indicated in Fig. 3, b.

Figure 3. A group of radial incisors (a), the shape of the slices (b) and the arrangement of incisors (c)

The technological result of the cutting process is to increase the yield of large fractions in the process of separating coal from the massif, reducing dust generation and specific energy consumption through the use of energy-efficient undercutting (6, 7, 9, 10, 12, 13, 15 and 16). Between the gap pillars 17 (Fig. 3, b) are destroyed by tangential incisors 4 (Fig. 3, c), which thus process up to 70% of the face area [8]. The disadvantages of this device are: the complexity of the design due to the different types of picks and pick boxes with three slots for fixing radial picks. The installation of radial picks in a group spaced apart from one another ensures the independence of cuts by each pick and therefore does not increase the likelihood of oversize output and does not change the intensity of coal grinding and dust formation during cutting.

When arranging incisors on the blades of a self-drilling auger, at least two incisors are usually provided in the cutting line and a sequential arrangement of their arrangement (Fig. 4, a). The exposure of the face is always one-sided, as a result of which there are large lateral loads on the screw actuator [3].

Figure 4. Sequential arrangement of incisors (a) and slicing scheme (b)

In recent years, research has been carried out to find new patterns for the placement of incisors. For example, in one cutting line, adjacent incisors are set with exceeding each other (on different circles) [13]. As the feed rate increases, one, then two, three, and finally four picks are involved in the cutting process. As a result, an approximately constant cut thickness is maintained over the entire range of feed rate changes, which ensures a reduction in specific energy consumption and an increase in grade [4, 14].

The use of paired picks on the screws, which provides a pair cut and a large cross-sectional area of the cut, and the corresponding sequential arrangement of their arrangement (Fig. 5) leads to a
reduction in the loads on the picks, to a reduction in the specific energy consumption and to an increase in the grade of coal in terms of particle size distribution.

**Figure 5.** Arrangement of paired incisors (a) and slices (b)

As established by numerous studies, in particular those cited in [12, 13, 15], with an increase in the cut thickness $h$, ceteris paribus, the specific energy consumption decreases, approaching asymptotically to a certain value depending on the strength properties of the formation, such as picks and cutting drum. These features will also be valid for the processes of separation of coal from the auger screws array with combined sequential-group schemes for arranging picks.

The picks of the rotor actuators separate the coal from the array with sickle-shaped shavings of variable thickness and cross-sectional area, each of which is characterized by the maximum thickness ($h_{\text{max}}$) and its current values ($h_i$). The maximum thickness of a slice per auger screw turnover is determined by the formula:

$$h_{\text{max}} = \frac{100 \cdot v_n}{n \cdot m_p}, \quad (3)$$

where: $v_n$ is the feed rate, m/min; $n$ - frequency of rotation of the executive body, rpm; $m_p$ - the number of incisors in the cutting line.

The current value of the thickness of the slice is determined by the formula:

$$h_i = h_{\text{max}} \sin \phi_i$$

(4)

where: $\phi_i$ is the current value of the angle of the position of the pick; D is the diameter of the cutting drum on the cutting edges of the picks.

Replacing the actual trajectory of the pick with a circle, expression (4) can be simplified as:

$$h_i = h_{\text{max}} \sin \phi_i \text{and when } \phi_i = \frac{\pi}{2}, \quad h_{\text{max}} = \frac{100 \cdot v_n}{n \cdot m_p}. \quad (5)$$

It is necessary to choose such values of $n$ and $m_p$ so that, with the smallest number of combinations, working with the accepted rational values of the thickness of the slices is ensured. It is known that the thickness of the cut can be increased by increasing the feed rate, reducing the frequency of rotation of the cutting drums and the number of picks in the cutting line (Fig. 6).
Relation of the change in slice thickness with change in feed rate and rotational speed of the executive body

where: $h_{\text{max}}$ is the maximum thickness of the slice; $h_{\text{min}}$ is the minimum thickness of the slice; $v_{\text{max}}$ - maximum feed rate; $v_{\text{min}}$ - minimum feed rate; $m_p = 1, 2, ..., 5$ - the number of incisors in the cutting line.

In modern combines, the rotational speed of the working bodies is usually a constant value. Sometimes a change in speed is achieved by switching the gear ratio of the gearbox or by replacing the gear pair. Operational change in the thickness of the slice is carried out by adjusting the feed rate. The maximum permissible cut thickness is limited by the overhang of the pick, or by the drive power of the combine. For normal operation, it is generally recommended [2, 4, 16, 17] that $h \leq 0.7l_p$, otherwise it is possible that the elements of the working auger actuator (pick box, the end surface of the blades) will come into contact with the face, which, when operating modern, high-speed combines are quite common. Therefore, when developing the design of the auger screws, picks, pick box and determining $h_{\text{max}}$, it is necessary to take into account the possibility of “fitting” the pick box into the camber of the cut.

In the region of half-free and semi-blocked sequential slices at $h = \text{const}$, the specific energy consumption (Fig. 7, curve 1) decreases with increasing width of the slice, reaching a minimum value ($t_{\text{on}}$), then increases to a steady-state value (Fig. 7).
With an equal slice thickness, the features of changing the specific energy consumption of the cutting, pair and group sections with a change in their width are preserved, including changes in the shapes of their sections. The undercut (curve 2) is characterized by a slightly lower energy consumption compared to a sequential cut (curve 1). A paired slice (curve 3) provides greater energy efficiency compared to both sequential and undercut. Under certain conditions, a group cut may be the most energy-efficient cut (curve 4). At present, there is no experience in testing auger actuators using cutting, pair and group sections. Therefore, further studies, modeling of the cutting process, the search for rational patterns for the placement of picks, laboratory research and industrial testing of screw actuators with cutting, pair and group sections are necessary.

3. Conclusion
1. The traditional layout of the incisors on the cutting drum of shearsers no longer meets modern requirements for particle size distribution, specific energy consumption and output of small classes of coal and dust.
2. Improving the efficiency of separating coal from the massif by screw executive bodies of shearsers can be achieved by a comprehensive technical solution, including:
   - the use of energy-efficient types of cuts in the arrangement of picks: cutting, pair and group;
   - substantiation of rational sequentially group schemes of arrangement of incisors on cutting drum;
   - development of a methodology for choosing rational parameters of sequentially group schemes for arranging incisors on cutting drum.

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