Increasing the coarse coal fractions yield during coal mining using shearer cutting drums

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Abstract. The paper analyzes the factors affecting the particle size distribution of the extracted coal mass by shearsers, and considers ways to increase the content of coarse fractions. The search for methods and technical solutions is coupled with the idea of increasing the cross-sectional area of the cuts by the choice of their rational forms, which makes it necessary to improve the arrangement of cutters on the executive bodies.

1. Introduction

Coal is one of the most valuable minerals that are important for the energy, chemical and other technological industries in Vietnam. Increasing coal production (Fig. 1) is currently of particular importance. The higher the volume of coal mined, the lower the cost of purchasing imported coal and the lesser economic dependence there is on other countries [1-3]. According to the long-term plan of the Vietnamese coal-mineral industrial group “VINACOMIN”, by 2030, coal production must be doubled compared with the current production. In connection with mining and depletion of reserves suitable for open-pit mining, it is planned to extract about 90% of the coal by underground mining.

The developed coal seams in Vietnam according to the mining and geological conditions of their occurrence can mainly be attributed to low-tech seams. For this reason, it is important to create a developed mining industry with intensification of production from low-tech coal seams, providing the specified face load, specific energy consumption ($H_w$), grain size distribution of coal ($W_d$) and standard completeness of coal excavation from developed seams.
World experience shows that in underground mining of medium-sized and powerful seams, complex fully-mechanized long walls, which mines pillars with large reserves of coal, are most effective [4, 5]. The removal of coal from structurally complex layers in the conditions of Vietnam can lead to a sharp increase in costs and volume of its non-recoverable reserves.

2. Results and discussion
Practically all fully-mechanized long walls on medium seam and thick seams with angles of incidence up to 35° are equipped combines having shearer cutting drums [6]. The advantages of such combines are their workability: combining the functions of separating coal from the mass of the reservoir and loading it onto the bottomhole conveyor; the ability to regulate the position of the cutting drums according to the coal height and self-tapping capacity, the workability of the shuttle and one-sided with the sweep technologies of excavation of the combines, their reliability and durability. For the foreseeable future, in the practice of combine mining on medium and high-stratum formations in the fully-mechanized long walls, there will be no alternative.

However, the process of coal extraction by such combines has significant drawbacks: instability of the operating mode, frequent stops, feed rate ($V_n$) varies over a wide range (Fig. 2), which lead to coal crushing and increased energy consumption. The main reasons for this situation are the peculiarities of the method of coal separation from the massif by the cutting drum and a multifactorial and random in nature dependence of the feed rate of combines on mining and geological and technological conditions.

![Figure 2. Change in feed rate ($V_n$) of the shearer during its continuous operation](image)

The principle of operation of modern rotor combines is based on the mechanical continuous separation of coal from an array by milling from an open surface with crescent-shaped cuts with a cutting speed of 2-4 m/s [7]. This method of coal separation from the massif is characterized by high manufacturability (simplicity, reliability, stability and intensity) and significant drawbacks: low particle size distribution of the coal mined ($W_d = 40\%$ of small classes), intensive dust formation and, as a result, high specific energy consumption [8 - 11] and the substantial costs of material means and labor for the suppression, deposition, binding and cleaning of explosive coal dust.

Increasing the particle size and productivity, reducing the energy intensity of mining and dust generation can be achieved by conducting a set of joint activities, including increasing cross sections of cuts, improving the cutter placement scheme, design of cutting and loading bodies and working modes of shearsers.

The particle-size distribution of the extracted mass correlates well with the specific energy consumption, with the average thickness of the cut (Fig. 3) and its change for a single cut (Fig. 4) with constant strength parameters of the coal massif and geometric parameters of the incisors and executive bodies.
Figure 3. Dependence of the specific energy consumption on the cut thickness:

a - zone of operation modes of the shearsers;
b - zone operating modes plow installations.

On the graph (Fig. 3), the specific energy consumption \( H_{wo} \) and the cut thickness \( h_o \) are given in relative units:

\[
H_{wo} = \frac{H_{wf}}{H_{wn}},
\]

where: \( H_{wf} \) is the actual specific energy consumption, kWh/t; \( H_{wn} \) - specific energy consumption in nominal mode, kWh/t;

\[
h_o = \frac{h_f}{h_n},
\]

where: \( h_f \) is the actual cut thickness, mm; \( h_n \) - nominal thickness of the cut, mm.

The specific energy consumption in the process of coal mining by modern combines with shearer cutting drums can be represented by the ratio [12-13]:

\[
H_w = \frac{P_{cp}}{60 \cdot Q} = \frac{A + B \cdot V_n}{60 \cdot B_3 \cdot H \cdot \gamma \cdot V_n} = \frac{A}{K \cdot V_n} + \frac{B}{K} = \frac{A}{K \cdot n_{cp} \cdot z \cdot h_{max}} + \frac{B}{K} = \frac{C}{h_{max}} + \frac{B}{K},
\]

where: \( K = 60 \cdot B_3 \cdot H \cdot \gamma \) and \( C = \frac{A}{K \cdot n_{cp} \cdot z} \), constant for specific conditions; \( P_{cp} \) - the power consumed from the network by motors drive cutting, kW; \( Q \) - productivity of the excavation machine during continuous operation, t/min; \( A, B \) - parameters of the energy characteristics; \( V_n \) - feed rate of the combine, m/min; \( B_3 \) - capture width of the executive body, m;

\( H \) - reservoir thickness, m; \( \gamma \) is the density of coal in the massif, t / m³; \( z \) is the number of incisors in the cutting line.

Formula (3) shows that with an increase in the feed rate \( V_n \) in the range of its allowable values at a constant frequency of rotation of the executive bodies, the specific energy consumption \( H_w \) decreases to a minimum value \( \frac{B}{K} \) (Fig. 3). The value of \( H_w \), which corresponds to \( \frac{B}{K} \), can be achieved, as indicated by Posin E.Z. [13], by coordinated regulation of cutting and feed rates, ensuring \( h = h_{constr} \) which with modern development of electric drives is quite feasible.
The second significantly influencing factor on the particle size distribution ($W_d$) and the specific energy consumption is the crescent-shaped cuts (see Fig. 4) made by the incisors of the rotor executive bodies. The current value of the cut thickness for a single cut varies from $h_{\text{min}}=0$ to $h_{\text{max}} = \frac{V_n}{n \cdot \omega \cdot z}$, and the specific energy consumption during the cutting process changes from $H_w \to \infty$ as $\phi \to \pi$ to $H_w = H_{w\text{, min}}$ when $\phi = \pi / 2$.

With an increase in the feed rate ($V_n$), the shape of the chips being cut off somewhat changes: the length of the upper half of the chips increases, the lower one decreases when their areas are equal $S_1 = S_2$ (see Fig. 4). The current value of the thickness of the slice ($h_i$) at a constant feed rate ($V_n$) and cutting speed ($V_r$) is determined by [14]:

$$h_i = \frac{2\pi \cdot V_n}{\omega \cdot z} \sin \phi_i$$  \hspace{1cm} (4)

when $\phi_i = \frac{\pi}{2}$ then:

$$h_i = h_{\text{max}} = \frac{2\pi \cdot V_n}{\omega \cdot z},$$  \hspace{1cm} (5)

where $\phi_i$ is the current value of the angle of the cutter position; $z$ is the number of cutters in the cutting line, $\omega$ is the angular speed of rotation of the screw.

The specific energy consumption varies per unit cut and is directly proportional to the change in the thickness of the cut. With an increase in the slice thickness of more than 80 mm, the cutting power consumption, with the existing design and cutter placement schemes at the executive bodies, decreases insignificantly (Fig. 3), approaching the corresponding asymptote – the theoretical minimum [13]. Excessive overgrinding of coal, determined by the crescent shape of single cuts, is inherent in all types of rotary actuators and cannot be eliminated.

The dependences of the specific energy consumption $H_w$ on the cutting pitch, constructed from experimental data [14, 15] (Fig. 5), have clearly expressed minimum values that correspond to the optimal value of the cutting pitch $t_{\text{opt}}$, and $t_{\text{opt}}$ depending on the depth of cut. With increasing chip thickness, the zone of optimal ratios approaches to smaller values.
Consequently, the possibilities of the traditional ways of increasing the efficiency of the process of separating coal from an array by the use of shearer cutting drums are largely exhausted. No new effective ways to increase the yield of large fractions in the mining process by changing the values of the executive bodies, cutters and their operating modes have yet been found [16, 17]. However, there is a possibility of increasing the particle size distribution and reducing the specific energy consumption by increasing the cross sections of cuts, which can be achieved by choosing a rational cut patterns (chequered, face, group cuts) or a combination of cuts. The possibilities of this search path are not sufficiently studied, connected with the need to improve and combine the types of working tools, search for more advanced sections of sections and the corresponding cutting-edge arrangements on the executive bodies.

3. Conclusions
1. Traditional ways of improving the quality of coal by particle size, reducing the specific energy consumption, and the intensity of dust formation in the processes of coal separation from the work face using shearsers and by increasing the thickness of the cut and spacing of cutters on cutting drums no longer provide meaningful results and are hardly used.
2. Improving the efficiency of coal separation from the massif is possible with a complex solution, including:
   - an increase in the sectional area of the cut using the pairing effect of chips and the formation of group and combined cuts;
   - improvement of cutter placement schemes;
   - search, justification and use of more efficient forms and cross-sections of cuts;
   - coordinated regulation of cutting speeds and the filing of executive bodies.

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