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ENERGY-SAVING MODULAR UNITS FOR SELECTIVE COAL CUTTING

The authors analyze coal cutting from the viewpoint of the least energy input of the process. A coal seam is assumed the medium with essential anisotropy of strength due to lamination, banding, jointing with sliding surfaces, normal jointing and weakening due to overburden pressure. It is shown that under such conditions, the lowest energy input of mineral mining is achievable through selectivity of the process. The scope of the discussion embraces feasibility and prospects of selective coal cutting and extraction in complicated ground conditions, both in longwalling and in narrow faces. The method of face operation, the cutting module and the front-end modular units have been proposed in the article. The unitized cutting modules are designed for energy-saving cutting of coal in a local face with the feasible selectivity of the process. The front-end modular unit is composed of the unitized cutting modules equipped with static, dynamic or hybrid action cutting heads. In terms of the front-end modular unit, the authors consider the method of longwalling, with local faces and parallel cuts, when coal is cut by sequential shears along the bedding. The front-end modular units are recommended for mining bedded deposits, e.g., coal, potash. As opposed to end-on cutting-loading units, the front-end modular units are efficient in long and short walls, in cutting either high-grade coal or in recovery of pillars and noncommercial reserves.

Key words: *coal, seam, face, cutting module, cutting, front-end unit, selectivity.*

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Introduction

At the present time, efficient underground mining of coal predominantly takes so-called high-technology (high-quality) coal strata and uses longwalling method, cutter-loaders and power-driven ploughing machine sets [1]. In poor ground conditions, in coal seams of complicated structure and in small working areas, the integrated mechanized coal face operation has much lower intensity and stability.

As coal reserves in high-quality seams are being depleted, it gets increasingly less possible to carry out coal mining in favorable ground conditions. Coal in zones of faulting, at boundaries of mine fields, in pillars and in complicated structure seams is unrecoverable with the modern high technologies, remains unclaimed and usually is irretrievable loss. For this reason, it is of current concern in all countries with the developed mining industry to intensify mining of low-technology (low-quality) coal seams and to enhance completeness of such coal extraction.

Efficiency of underground coal mining is achievable through:

— enhancing coal extraction ratio owing to coal mining in low-quality strata, at the boundaries of mine fields, in zones of faulting and in pillars, currently assumed non-commercial reserves for different reasons;

— reducing energy input of coal cutting;

— improving quality of coal product in terms of grain-size composition and ash content;

— elevating capacity of mining machines.

The modern stage of development of mechanized coal cutting attempts to reach objectives of: automated control of support [2] as a tool of adapting cutter–loaders to various ground conditions [3–5], employment of coal cutting machine sets in strata having complex hypsometry [6, 7] and customization of the machine sets to heavy roofs [80] and dynamic loads [8]. Although these approaches undoubtedly contribute to mining safety and production output enhancement, they meet the challenges not in full measure.

The only way of concurrent handling of the set tasks is selective cutting of coal and engineering of the appropriate equipment.

This study aims to find and evaluate efficient methods of coal cutting by mining machine sets at reduced overcrushing, energy input and dust generation.

Analysis and method

The key criteria of coal cutting efficiency in a production face are the stability of coal mining machines in rational operating modes under varied ground conditions, machine capacity, grain-size composition and ash content of coal, and the specific energy consumption. The latter is the key characteristics of coal cutting efficiency as the specific energy consumption is in correlation with the grain-size composition of coal and depends on coal cuttability, content of solid rock intercalations and cutting thickness at the constant parameters of cutting bits.

The specific energy consumption of coal mining, for instance, by cutter–loaders, is determined from the known relations:

$$H_W = \frac{P}{60 \cdot Q} = \frac{A + B \cdot V_f}{60 \cdot B_{cut} \cdot H \cdot \gamma \cdot V_{ftech}} = \frac{A}{K \cdot V_f} + \frac{B}{K} = \frac{A}{K_h \cdot h} + \frac{B}{K}, \quad (1)$$

where P is the mains power taken by machine motor, kW; Q is the technical capacity of the mining machine in continuous operation, t/min; A, B are the energy characteristics of the mining machine; V_f is the feed velocity of the mining machine with regard to constraints, m/min; B_{cut} is the cutting width of the cutting head, m; H is the coal seam thickness, m; γ is the coal density, t/m^3; V_{ftech} is the technical velocity of feed; K is the productive time factor; K_h is the cutting thickness factor; h is the cutting thickness, m.

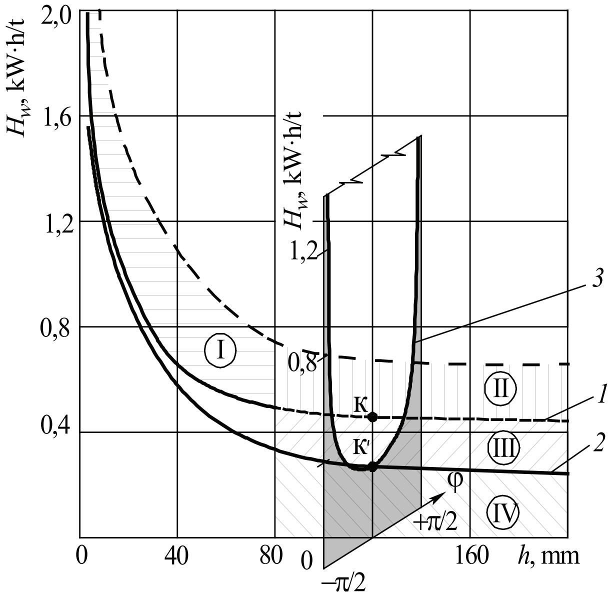

Fig. 1. The energy input, cutting thickness and cutting method relation:

1 — drum shearers and ploughs; *2* — single reference cutter; *3* — variation in H_w per cut for cutting machines with rotary and dislodging drums

In the graphical chart of the specific energy consumption and the cutting thickness in **Fig. 1**, zone I depicts operation of the modern mining machines with rotating cutting heads and ploughing machines. It is seen in the figure that reduction in energy input by increasing the cutting thickness is expedient to 80–100 mm (zone I). The further increase in the cutting thickness (zone II) is unfeasible for the modern rotor machines as it results in excessive dynamics of loading. Due to a scimitar shape of the cut, the energy consumption H_w grows as a function of cutting bit position (curve 3) and becomes a source of small coal fragments, fine dusting and overheat of the cutting bits. The value of H_w per single cut is shown by curve 1. The averaged value per cut is marked by the point K. Accordingly, the energy input reduction requires eliminating the scimitar shape of cuts and increasing the cutting thickness to 80–100 mm and more (zone III, curve 2 and the point K′).

Coal seams are anisotropic laminated material with oriented structure; coal properties vary with orientation of destructive force relative to lamination and jointing. In perpendicular direction relative to production face plane, coal strength is mainly affected by the face slip, especially in brittle and jointed coal in complex structure seams. Convergence of enclosing roof and floor will in a greater or lesser degree deform weaker layers, maximum strains and displacements will envelope the weakest layers at the roof or floor depending on the roof and floor rock displacement in the face slip area.

The further reduction in the energy input is related with selectivity of operation at the coal face (zone IV), i.e., the place, direction and thickness of cutting is to conform with the coal seam structure, joining and face slip which are consistent with the lowest breakage resistance.

Thus, modern cutting and ploughing machines, as well as cut-and-plough assemblies, enjoying stable advancement and commercial application, break rocks by continuous surface cutting. Considering their structure, they fail to implement selective cutting and to make thicker cuts as dynamics of loading overgrows. Moreover, such machines feature high energy inputs, increased wattage in active cutting area, overcrushing of produced coal and excessive dust generation.

Selective cutting is feasible with some winning machines, in particular, with section-type cyclic-action machines [10] applicable in front-end cutting of coal. A special feature of such machines is that cutters are mounted on each section of powered support, or on the next nearest section, or on a special platform.

The fluid-operated front-end cutting unit AFG (**Fig. 2**) [11] has been designed for weak and fair coal in flat seams 1.5–2.2 m thick, with unstable wall rocks. The unit includes powered support with girders, section-type cutting heads with hydraulic jack drives, conveyor and hydro- and electric equipment.

Coal was broken throughout the length of the longwall, by independent section-type cutting heads that broke lower

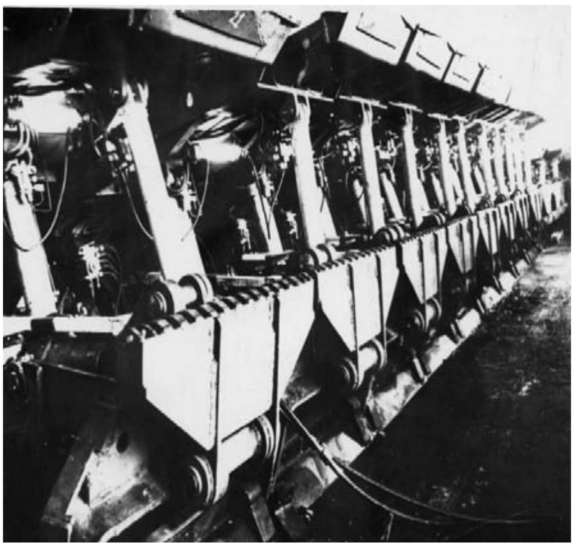

Fig. 2. Cutting unit AFG

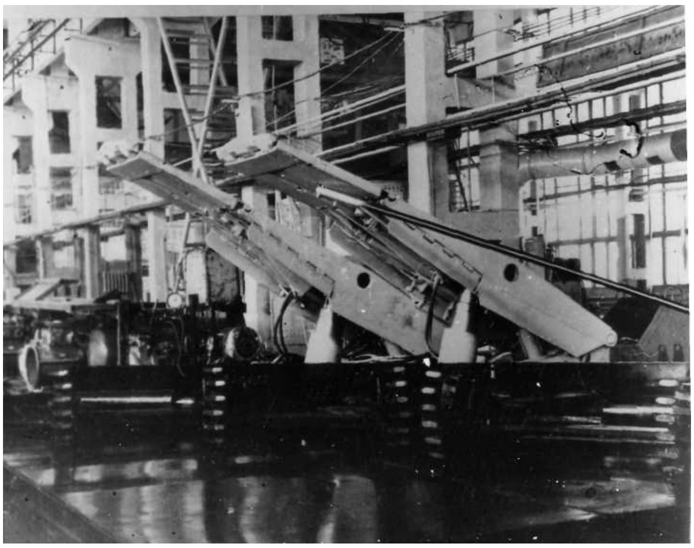

Fig. 3. Cutting unit AGK-8

part of coal and loaded coal on the conveyor. The top coal up to 0.5 m thick was caved by extension-type shearers.

The trial of the cutting unit in a mine proved cuttability of coal seams by the hydraulic-drive cutting heads at the cutting thickness h = 70–100 mm, energy input H_w=1.0 kW×h/t and capacity of 1000 t/day.

The cutting unit AGK-8 (**Fig. 3**) [12] is intended for driving assemblage rooms in steep coal seams. The operating conditions tolerate coal seam thickness of 0.7–1.5 m, coal dip angle of 40–90°, coal and dirt band cuttability of 150 and 200 kN/m, respectively. The cutting unit has modular structure. The cutting heads are driven hydraulically.

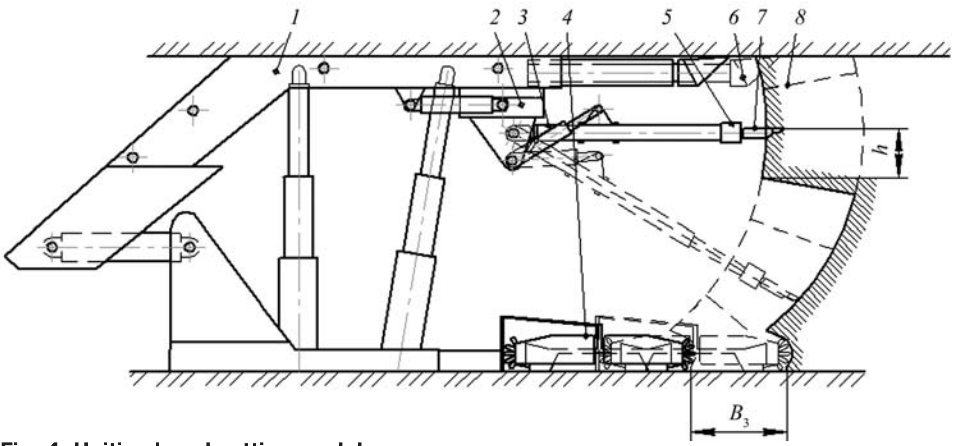

Fig. 4. Unitized coal cutting module

Bottom coal was cut by bidirectional rotary comb-type cutting heads. The undercut top coal was caved by shearers that simultaneously acted as the support elements. Aiming to balance cutting force reactions and to synchronize operation, the cutting heads were grouped. The groups of the cutting heads performed cutting in opposite directions. Each group consisted of three comb-type cutting heads powered by two booster jacks.

The test outcome: cutting thickness was up to 100 mm, cutting force up to 20 kN, the sheared coal thickness to 0.2–1.0 m at the boost up to 200 kN. The energy intensity of cutting was 0.42 kW·h/t. The tests confirmed functionability and exploitability of the cutting unit.

The combination method of coal cutting allows considerable reduction in the energy consumption of coal breakage. The modular structure of the cutting unit enables manufacturing cutting units of any length, either for pillar mining or for longwalling.

Nevertheless, in spite of all capabilities listed, the machines have failed to ensure selective coal-face cutting.

Engineering solution

An alternative to available mining machines in this situation may be the known though yet scarcely used unitized section-type cutting modules [13]. The unitized cutting modules are included in the front-end action modular units for energy-saving selective cutting of local faces. Selective extraction of mineral is feasible, too. The modular structure of such units enables operation both in high-productive longwalls and in shortwall faces, in extraction of mineral reserves from pillars or on limited-area low-quality coal sites.

Generally, a unitized cutting module (**Fig. 4**) is composed of such elements as: supporting base represented by powered support section *1*, rotating rack *2*, mechanical arm *3*, plough–conveyor *4*, rotating device *5*, canopy group with a shearer *6* and fast-mounting cutting head *7* of static or static–dynamic action subject to coal and rock mass hardness.

The module implements front-end cutting of coal by concurrent parallel cuts. A local face is broken by selective full-width shearing over bedding planes in the line of the longwall advance. The sequence of shearing across the coal seam thickness depends on the structural properties of the seam and is governed by the standards of minimum breakage energy input per cycle, the process flow stability and rock breakage free from oversizes. The top coal is cut by the shearing canopy group, the bottom coal is cut by the plough–conveyor group adjusted at the floor–seam boundary.

The analytical formulas have been derived to find technical capacity of the cutting module (2) and front-end modular unit (3):

$$q_m = l_L l_s H\gamma / T_c \, , \tag{2}$$

$$Q = \frac{T\gamma S K_{aa}}{\frac{1}{hV_{cut}} + \frac{1}{hV_p} + \frac{K_{sa}}{V_{st}H_{cut}} + \frac{2}{l_s V_p}\left(1 - \frac{h}{H_{ctu}}\right)}, \tag{3}$$

where l_L is the length of local face, m; l_s – is the length of shear, m; H is the coal seam thickness, m; T_c is the cycle time, s; T is the operation time of the cutting module, s; γ is the coal density, t/m^3; S is the face area, m^2; K_{aa} is the active face area factor; h is the cutting thickness, m; V_{cut} is the cutting bit velocity in cutting, m/s; V_p is the cutting bit velocity in positioning, m/s; K_{sa} is the coefficient of the support section advance; V_{st} is the support section travel velocity, m/s; H_{cut} is the cutting thickness, m.

Test results

Manufacture of the unitized cutting module was preceded by bench testing of two fullsized engineering prototypes of the cutting modules with hydrostatic power drives. Rock mass was simulated by layered coal–cement block with cuttability from 60 to 350 kN/m [14].

The cutting module was composed of two sections of hydraulic shield support equipped with coupled cutter heads. Hydraulic drives maintained two cutting modes: constant cutting velocity and constant cutting force. The cutter heads performed arched motions with the help of two hydraulic jacks.

The tests of the cutting module have proved that:

— selective cutting with manual, programmable or automated control is feasible;

— hydrostatic power drives enable large cross-section cuts, i.e., specific energy consumption is lowered;

— loads on the cutter are reduced with hydropneumatic accumulators included in the drive design [15].

After the tests of the cutting module on coal–cement block, the range of the experimental values of the cutting forces is located under the range of the experimental cutting thicknesses $Z = f(h)$ [14]. The lower level of average load on the cutter as compared with the calculated values at the same cutting forces is an important factor giving a cumulative estimate of the process of cutting by a mechanism with the hydrostatic power drive, having soft mechanical characteristic in terms of cutting velocity.

Discussion

The operation of the cutting module in mineral mining features: stable shearing at a thickness $h = 0.10 \div 0.3$ m, selected place and direction of shearing, considering strength anisotropy of rocks under cutting and, accordingly, at mineral extraction selectivity. At the fixed shape of the cutting cross-section, nonuniformity of the cutting velocity results in reduction of loading dynamics, improvement of grain-size composition and enhancement of production output, as well as in decreased energy consumption and lower dust generation. Finally, this allows the enhanced quality and volume of production and the cutout cost per unit product.

The unitized cutting modules with the programmable control enable generating robotized mining machine sets for four key areas of operation:

— longwalling with high concentration of coal-face work;

— room-and-pillar mining;

— recovery of pillars and non-commercial reserves currently assumed nonrecoverable;

— special purpose operation.

The special purpose operation modules are for:

— driving assembly rooms;

— making initiation cuts (when included in cutting–loading machine sets);

— cutting in faulting zones.

Conclusion

Selectivity can become a feature of mechanized coal mining in the immediate future. The cutting modules of the front-end action machine sets to implement selective coal cutting ensure:

— enhancement of coal extraction ratio;

— reduction in energy input of cutting;

— improvement of grain-size composition and, thus, coal product quality;

— essential increase in production output;

— mining safety improving.

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