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FEATURES OF ELEMENTARY BURST FORMATION DURING CUTTING COALS AND ISOTROPIC MATERIALS WITH REFERENCE CUTTING TOOL OF MINING MACHINES

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The paper considers the cutting of brittle coals and rocks by a single cutter of a mining machine, in contrast to the generally accepted integral approach, different from the standpoint of the formation of successive elementary bursts that make up the cut. The process of the formation of an elementary bust in time is viewed as successive phases. Due to the complexity and multi-factor nature of the process, preference is given to experimental bench studies using reference cutters, isotropic materials, and real rock blocks.

The bursting parameters values greatly influence the time of static forces action, the peculiarities of the formation of stress fields in the undercutter zone of the rock mass and the conditions for the emergence and development of main cracks in the near-cut zones during the cutting process. The accepted phase-energy method of analyzing the process, which most closely matches the structure of the studied process, revealed a more significant, than previously expected, effect on the cutting process, variability of cutting speed and potential energy reserve in the cutter drive. The paper discusses the possibility of purposeful formation of the parameters of elementary bursts. It describes new ways to improve the efficiency of cutting coal and rocks, in particular, reducing the maximum loads and specific energy consumption. It also considers the possibility of reducing the grinding of the rock mass and dust formation.

Key words: coal; rock; mining machine; cutting; reference cutter; elementary burst; bursting phases; main crack

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Introduction. At the present stage of underground coal mining development, the longwall faces equipped with a complex mechanized combine or plow coal face systems have become widely used. At the same time, the main volume of extracted coal is mined during the development of thick and medium thickness flat seams using double-drum shearers.

Shearers and planers separate the coal from the rock mass by continuous cutting of the working face surface. They are reliable, high-tech, provide intensive mining, can work in unidirectional and bidirectional modes without preliminary formation of stables. There is no alternative for this type of equipment in the nearest future. However, they are characterized by features that significantly inhibit the growth of their efficiency: excessive overgrinding of the separated coal mass, dust formation [13] and limited use for the hard rocks due to insufficient durability of the working elements [6]. These features are integrated into the cutting method of this equipment.

Some specialists noted the reduction in the quality of coal particle size with the introduction of the first narrow-web cutter-loaders with rotors. Various technical solutions were proposed for increasing the particle size, including rotors for coarse cutting, tangential cutters, disk rolling cutters, and units with a combined working tool. With an increase in the cross-section of cutting the dynamics of loads increased, the reliability and stability of equipment working in rational modes decreased.

The stoping machines have greatly changed and developed. The driving power, the metal content, and the intensity of the cutting process increased manifold. High load dynamics [5] and specific energy input [14] are no longer critical limiting factors. However, the quality of the mined coal was not improved.

The paper [13] presents the distribution of the granulometric coal composition in percent when it is mined by modern mining equipment in the mines of the Vorkuta deposit (see table). With an average cut thickness of h = 4.0÷6.0 cm the extraction of high-grade coal (classes 6-13, 13-25, 25-50 mm and more than 50 mm) amounted to 5.7-60.4 % for planer GH, for shearer SL300it was 60.7 %, and for shearer MB12 – only 32.3 %. The lower output limit of volatile coal dust is 6-11 % of the total volume and is mainly determined by the features of the interaction of the cutters with the rock mass. The yield of small fractions (classes 0.5-1.0; 1.0-3.0; 3.0-6.0 mm) was respectively 32.7; 31.4 and 57.3 %; dust output during mining by plow – 6.8 %, with the SL300 shearer – 7.8 %, and with the MB12 shearer operating on low-thickness seams, 11.2 %. With existing designs of planers and shearers for medium-thickness seams, the upper limit for the yield of high-grade coal (> 6 mm) is about 60 %.

The granulometric composition of mined coal, %

Coal	Size, mm	Planer GH 5.7	Shearer SL300	Shearer MB12
Sized coal	> 50	10.9	9.8	2.3
	13-50	33.4	30	18.5
	6-13	16.1	20.9	11.5
		Σ = 60.4	Σ = 60.7	Σ = 32.3
Fines	3-6	12.1	13.5	26.5
	1-3	14.4	14.7	22
	0.5-1.0	6.2	3.2	8.8
		Σ = 32.7	Σ = 31.4	Σ = 57.3
Dust	0.2-0.5	4.5	5.5	6.4
	0.0-0.2	2.3	2.3	4.8
		Σ = 6.8	Σ = 7.8	Σ = 11.2

Formulation of the problem. Previous studies have shown that the volume of coal separated from a face and crushed to the level of nonvolatile fines and volatile dust is about 40 % of the total production, this material is classified as waste and losses, which significantly increases costs and reduces the efficiency of underground coal mining.

It should be noted that according to [1], in the overall balance of energy costs in cutting coal and rock (Fig.1), crushing and grinding of coal accounts for 50-78 % of the energy supplied to the business end of the excavation machine, grinding during friction – 20-46 %; the formation of cracks – up to 10% and energy dissipation during deformations of the mass and machine parts is about 2 %.

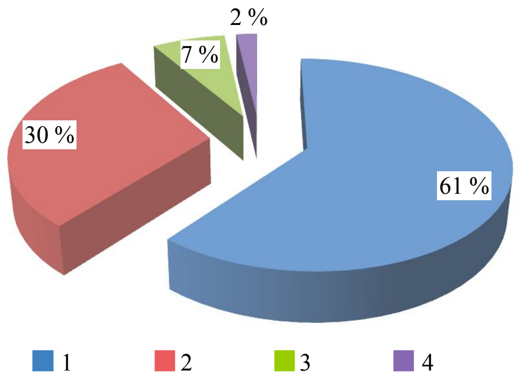

Fig.1. The distribution of energy components of the cutting coal process
1 – crushing and grinding; 2 – grinding with friction; 3 – cracking; 4 – energy dissipation during mass deformations and machine parts

As can be seen from the data, the relative values for energy costs and volumes of the crushed product are the same: the volume of high-grade coal is 60 %, while about 61 % of the total energy is supplied to the operating part of the machine, 32 % of fine coal volume and 30 % of energy consumed for grinding.

Despite the noted drawbacks, the process of coal cutting, as compared to other known methods of longwall mining, is preferable for use in mining machines in the foreseeable future [7, 8], especially since the possibilities for its improvement are far from exhausted.

The theoretical description of the cutting process is most fully represented by the classical experimental-statistical theory of coal and rock cutting [8]. Based on its fundamental provisions, it is possible to formulate directions for further research on the separation of coal from rock mass [7], which narrowed down to the need to substantiate the parameters of the processes and technical means that reduce the irregularity and narrow the load spectrum, increase productivity and improve the grain size distribution of mined material, to justify the need for selective extraction of minerals with a given safety of mining operations, i.e. to increase the efficiency of mining machines.

Thus, it is necessary to study the process of cutting brittle coals and rocks from the standpoint of identifying patterns of formation of successive elementary bursts that make up any slice.

Generally, the cutting of brittle coals and rocks is a very complex thermo-gas-physical-mechanical process, which is implemented in the form of successive elementary bursts with friction sparking, heat radiation, dust, and generation of seismic, acoustic and electromagnetic waves [7-9, 12, 16, 18, 19, 21], and the process of coal mining is accompanied by increased methane emission [17, 20] and redistribution of rock pressure in the stoping zone [2, 11].

If we the research only the mechanics of coal cutting with a single cutter, then we should find the most significant and relevant direction: the study of the regularities of the formation of successive elementary bursts in the process of cutting brittle coals and rocks. According to the features of the methods and techniques of research, this area should be divided into three related topics:

1) study of the formation phase of elementary bursts;

2) study of the formation of the stress field in the undercutter zone when moving the cutting tool during bursting;

3) study of the conditions for the occurrence and development of main cracks.

Research method. Due to the presence of multiple factors, the variability of the conditions and the probabilistic nature of the realization of the influence of factors, any of the selected areas can be adequately evaluated only in the case of experimental studies with preservation of the physical-mechanical nature of the process.

The study of the formation phase of the elementary bursts is aimed at identifying the factors that most significantly affect the parameter values, the force, and energy characteristics and the identification of patterns of formation of the elementary bursts phases during coal cutting coal a single cutter.

The power characteristic of successive elementary bursts $Z_c = f(h,t)$ is the change in cutting force at a constant cutting speed (V_c = const) during the time t of formation of the cycle of an elementary burst. Graphically, it is represented (Fig.2) by successive phases: stripping – 1ph, crushing-grinding – 2ph, forming the compaction core – 3ph and burst – 4ph. The energy characteristic $W_e = f(h,t)$ of successive elementary bursts is the distribution of the energy consumed in the phases of the elementary bursting at V_c = const during the cycle T_c.

The highest energy costs are accounted for by the main and auxiliary – 1, 2 and 3 phases – up to 98 % of the total energy spent during the elementary bursting cycle, and in the burst phase (obtaining the finished product) less than 2 % of the W_e is consumed [9].

In the 3rd phase, in front of the edge of the moving cutter, the contact area of the cutter with the coal in the phase of rock crushing, the stress in the undercutter zone and its force sharply increase. When local defects and numerous micro-

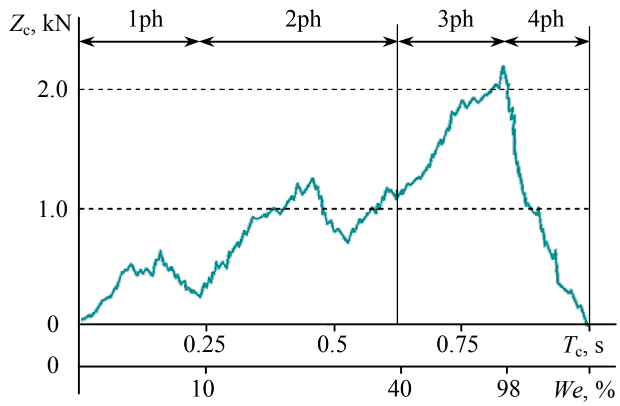

Fig.2. Ideal elementary burst characteristics

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cracks appear in the undercutter zone, a trunk crack arises (beginning of the 4th phase), which develops in the direction of the cutter and towards the open surface.

Here, the most important goal of research can be the identification of the very possibility of the redistribution of energy costs across the phases of a cycle of successive elementary bursts and the redistribution of energy costs from phases 1-3 to the main 4th phase of bursting.

The physical essence of the process of forming successive phases of elementary bursts is that after reaching the maximum effort $Z_{c.max}$ on the tool (at the end of the 3rd phase) and the onset of the main crack, its growth rate in the 4th phase significantly exceeds the speed of the tool. The leading surface of the burst is formed, it is generally at an angle to the plane of cutting and to the open surface. Upon further movement of the cutter, the cutting edge cleans (in the 1st phase) the surface of the burst up to the cutting plane. At the same time, energy is spent on friction and grinding of coal, mainly by abrasion, since in this phase of elementary bursting the cut thickness h is small and commensurate with the radius r of rounding of the cutting edge of the cutter ($h \leq 2r$).

With the deepening of the cutting edge of the moving cutter (2nd phase), the sheared pieces of coal accumulate on its front surface and are crushed. The compaction core (3rd phase) and the general area of stresses in the near-cut zone are formed, which are accompanied by an impulsive increase in the stresses in the rock mass and the sizes of the zones of increased stresses and cutting forces.

The formation of such a structure of successive elementary bursts is characteristic of the process of cutting brittle rocks at a constant speed (combines, plow installations, units), which is significantly less than the velocity of propagation of a main crack in the rock mass at critical stresses. When changing the parameters of the cutting mode (cut thickness, cutter velocity vector to the direction of stratification or the predominant fracture of the mass), the parameters of successive elementary bursts and the structure of the force and energy characteristics significantly change.

There are many forms of elementary bursts. The variability of their forms and the values of their parameters are usually estimated by probabilistic characteristics. It has been established that mainly (more than 90 %) bursts are cut in something like triangular shapes. The probability of triangular shapes occurrence is higher with the increase of coal brittleness, cut thickness and decrease in the cutting angle [8].

Each burst is preceded by the formation of a local zone of stresses in the undercut zone of the mass and the occurrence and propagation of the main crack. When cutting coal or rock with a single cutter, it is always possible to choose a cutter movement in the direction of their stable fracture, stratification or layering, which will ensure the propagation of the main crack in a given direction having the lowest resistance.

In this case, the relative energy costs of stripping (1st phase), crushing and grinding (2nd phase) can significantly decrease. The total energy for a single elementary burst will also decrease. This technology can be implemented with the development of selective methods of separating coal from the rock mass [14].

The study of the formation of the stress field in the near-cut zone of the rock mass when moving the cutter during the cutting process has emerged as a necessary link in identifying patterns of development of each phase of the sequence of elementary burst.

In general, the parameters of the stress field in the undercutter zone depend both on the cutter parameters, its mode of operation, and on the rock mass structure, the direction of movement of the cutter relative to this structure, the degree of deformation and displacements of the structure elements relative to each other and to the cutter. All this can have a significant impact on the ratio of compression, shear and tension stress in the near-cut zone and on their mutual displacements when the tool moves.

It is natural to assume that more stable structures and parameters of stress fields and an elementary burst process can be obtained by cutting with unchanged (quasi-isotropic) strength properties. The model (Fig.3, *a*) of the cutting process of an ideal isotropic array [15] was considered, which

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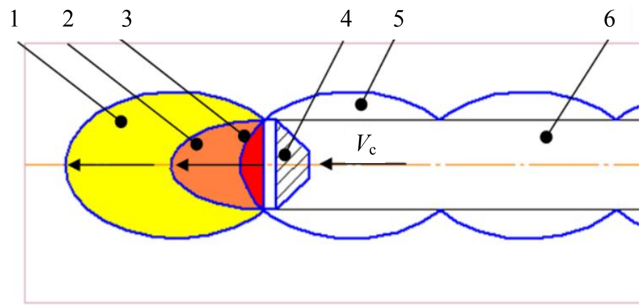
a



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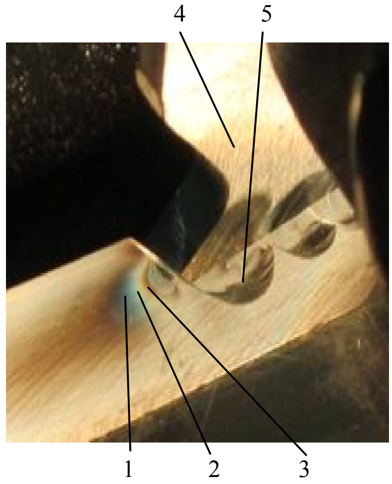

Fig.3. Formation of the stress field in the undercuts zone: *a* – model; *b* – experiment
1 – low stress field; 2 – maximum stress field; 3 – the boundary of the main crack; 4 – cutter; 5 – trace of elemental burst; 6 – the trace of the stripping (in fig. 3, b the trace is not visible)

can be taken as the starting point for further studies of more complex structural models of the rock mass. The model considers the following: the field of weak stresses; maximum stress field; boundary of the top of the main crack; cutter; trace of an elemental burst; and trace of stripping. In the process of cutting in the undercut space, an elastic deformation zone, zones of residual deformation and damage exist simultaneously, occupying adjacent spaces, displacing and successively replacing each other during continuous movement of the tool.

To check the adequacy of the considered model, experimental studies of the process of cutting an isotropic material were carried out, which was chosen as transparent acrylic glass. It made it possible to significantly reduce the influence of multiple factors and randomness on the process of formation of a stress field and the parameters of elementary bursts. On the one hand, we defined modes that exclude the formation of drain bursts, determined by the phenomenon of material creeping at low cutting speeds, on the other hand, we found high-speed modes following the conditions of thermal cutting.

The research process was carried out on a special stand [15] by cutting a plate of acrylic glass with a cutter with reference parameters except for the cutting-edge width (10 mm). The framed glass was fed to the fixed cutter by rotating the screw. During the cutting process, acrylic glass was illuminated through a special device with plane-polarized light, which provided observation, photo- and video recording of successively formed stress zones, the emergence, and growth of main cracks, the formation of an elementary burst phase and the cut surface (Fig.3, *b*). We noted the pulsating movement of zones of weak and maximum stresses and the boundaries of the main crack.

The field of maximum stresses occurs on the contact line of the cutter with rock mass, increases in size mainly in the direction of the cutter movement, at the moment of rapid growth of the main crack it separates from the cutter, moves along with the boundary of the main crack and disappears with a burst, to reappear at the subsequent contact of the cutting edge of the tool with the rock mass.

The shape of the elementary bursts resembles the shape of a seashell (Fig.4) with characteristic lines of closed arcs covering the entire surface of the burst. At the boundaries of these arcs, microcracks are observed that coincide with the directions of tool movement. There are stable alter-

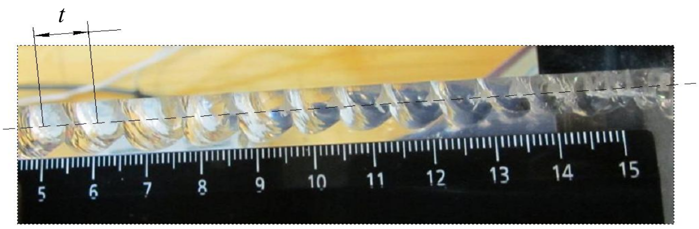

Fig.4. Characteristic sequence of traces elementary bursts in the cut
t – burst step

nations of successive elementary bursts, their shape, and size, phase alternation in the process of forming each elementary burst (see Fig.3, *b*).

Such stable features of the formation of a stress field and parameters of elementary bursts in the process of cutting an isotropic material (with a stable distribution of strength properties) confirm the possibility of purposeful formation of the structure and parameters of elementary bursts in the process of cutting and anisotropic materials, but with a stable distribution of strength properties, in particular separation of coal from the mass with working tool of mining machines. However, the peculiarities of the process of the emergence and growth of main cracks in the near-cut zones of the coal mass during the cutting process and their role in the formation of loads, the particle size distribution of coal being separated and in the energy costs of the elementary burst phases have not been adequately investigated.

The study of the conditions for the occurrence and development of main cracks in the near-cut zone of the mass during the cutting process was carried out by many researchers (in particular, Academician A.V.Dokukin, Prof. A.G.Frolov [3]). The issue is very important for the conditions of separation of minerals from anisotropic fractured-layered rock mass, which include coal seams.

The coal seams consist of layers weakened by the burst planes and systems of skew-cutting fractures separated by cracks (with traces of slips) into blocks. The blocks are divided into smaller separate closed cracks belonging to normal fracture systems, as a rule, rather stable in terms of geometrical parameters and intensity. Such a structure of the coal mass cannot but influence the conditions for the emergence and growth of the main cracks in the near-cut zone of the coal mass, their parameters, i.e., on the formation and, therefore, on the distribution of energy in the phases of the elementary cleavage.

Of particular interest are: the dependence of the critical stress in the near-cut zone on the time of the force effect of the cutter; the influence of the energy supplied to the cutter and the potential energy reserve in the drive of the cutter on the conditions for the occurrence and propagation of main cracks during an elementary burst cycle.

To identify the dependence of the burst waiting time on the applied quasi-static load, which is less than the critical value, bench experimental studies were carried out [4], as a result of which approximated dependences of maximum static cutting forces on the burst waiting time (Fig.5) were obtained with a cut thickness of 3-6 mm and its slotted shape. Each point on the graph reflects the averaged result of a set of experiments under the same conditions. The dependence of the maximum (quasistatic) cutting force on the time of the load, in general, can be represented by the formula

$$\bar{Z}_{\text{p}(t)} = \bar{Z}_{\text{p.r}}\left(1 - \lambda \ln(t')\right), \quad (1)$$

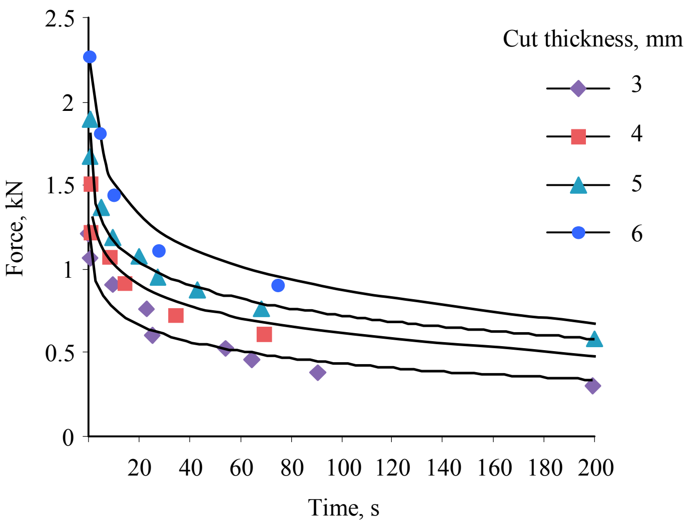

Fig.5. The dependence of the waiting time of the burst from the static forces acting on the cutter

where $\bar{Z}_{\text{p.r}}$ – medium peak (reference) value of cutting force at constant cutting speed; λ – coefficient characterizing brittle plastic properties and coal fracturing; t' – relative time from the moment of application of the load to the beginning of the burst.

Discussion of the results. The obtained results confirm the possibility of significantly reducing the loads on the cutters, or the destruction of stronger rocks, by changing the time of quasistatic loads application.

Considering the features of the single burst process (see Fig.2) and the sequence of bursts during coal cutting from the standpoint of the mechanics of the emergence and development of main cracks and the kinetic theory of fracture of brittle arrays, it can be noted that the cutting front of cutting force is formed with an increase in the thickness of the cut, coal crushing on the front surface of the tool and the increase in the number of small cracks around the compaction core. The steepness of the descending part is determined by the peculiarities of the development of the main crack, the length, and surface area of which depend on the thickness of the slice, the potential energy in the water cutter and the stress at the crack pole.

It is known that for the emergence of the main crack the stress in the undercut of the rock mass, near the cutting edge of the tool, must be greater than the critical stress at the crack pole after its occurrence ($\sigma_{cra} > \sigma_{cri}$), as part of the energy is spent on the formation of small cracks. The tensile stress at the crack tip at the beginning of its growth should also be greater than the critical one:

$$\sigma = \sigma_{cri} q = \sigma_{cri}\left(1 + 2\sqrt{c/r}\right), \quad (2)$$

where q – stress concentration factor; c – length of half of the central crack, micron; r – crack tip radius, μm.

Thus, the stress formed by the supply of energy to the main crack is equal to the product of the critical stress and the stress concentration coefficient, the values of which depend on the ratio of the half-length of the crack to the radius of the crack tip.

As follows from (2), the radius of the crack tip affects the speed of the main crack propagation. In brittle coals, the distance between closed endogenous microcracks, with the implementation of which the main crack propagates, is 1-10 mm. When critical stresses are reached at the crack tip, structural elements are displaced along the planes of endogenous cracks. The radius at the tip of the cracks can be defined as the distance between endogenous cracks or half the crack length of $0{,}5\ell_{cra.e}$, depending on the cutting direction. Such displacements cause the consumption of the surface energy of cracks to be 101-103 times greater than with the propagation of cracks in homogeneous materials and a corresponding decrease in the propagation velocity of the main crack. Consequently, the propagation velocity of the main crack in inhomogeneous fractured mass (coals) can be represented as

$$V_{m.cra} = k_s k_r \sqrt{E_e/\rho_e}\,, \quad (3)$$

where k_s − material structure factor; k_r – crack tip radius coefficient; E_e − elastic modulus, MPa; ρ_e − material density, kg/m^3.

In this case, the propagation velocity of the main crack will be significantly lower than in homogeneous materials, and it may turn out to be of the same order or so close to the speeds of movement of the mining machines cutters of that it will significantly affect the formation of the parameters of elementary bursts.

The formation of the elementary burst characteristics can be ensured by changing the quasi-static load and the time of its application, and when the main crack arises, by maintaining stress at the crack pole by supplying potential energy to the cutter drive hydraulic cylinder from the pneumatic-hydraulic accumulator [22].

The features of the stand with a hydraulic drive are [10]: the possibility of cutting the coal block at a constant (constant) speed (with the pneumatic-hydraulic accumulators disconnected); the possibility of cutting in the mode of constant force action (with pneumatic hydraulic accumulators connected to the hydraulic system) and a small inertial mass of moving parts of the cutter drive. The amount of potential energy stored by the pneumatic-hydraulic accumulators is proportional to the pressure of the working fluid in the hydraulic system, i.e., proportional to cutting force.

When cutting coal at a constant speed, the cutter only periodically creates stress in the rock mass, since the forward bursts interrupt the contact of the cutter with the mass. To ensure the mode with a constant force effect of the cutter, a reserve of potential energy in the drive is necessary to impart to

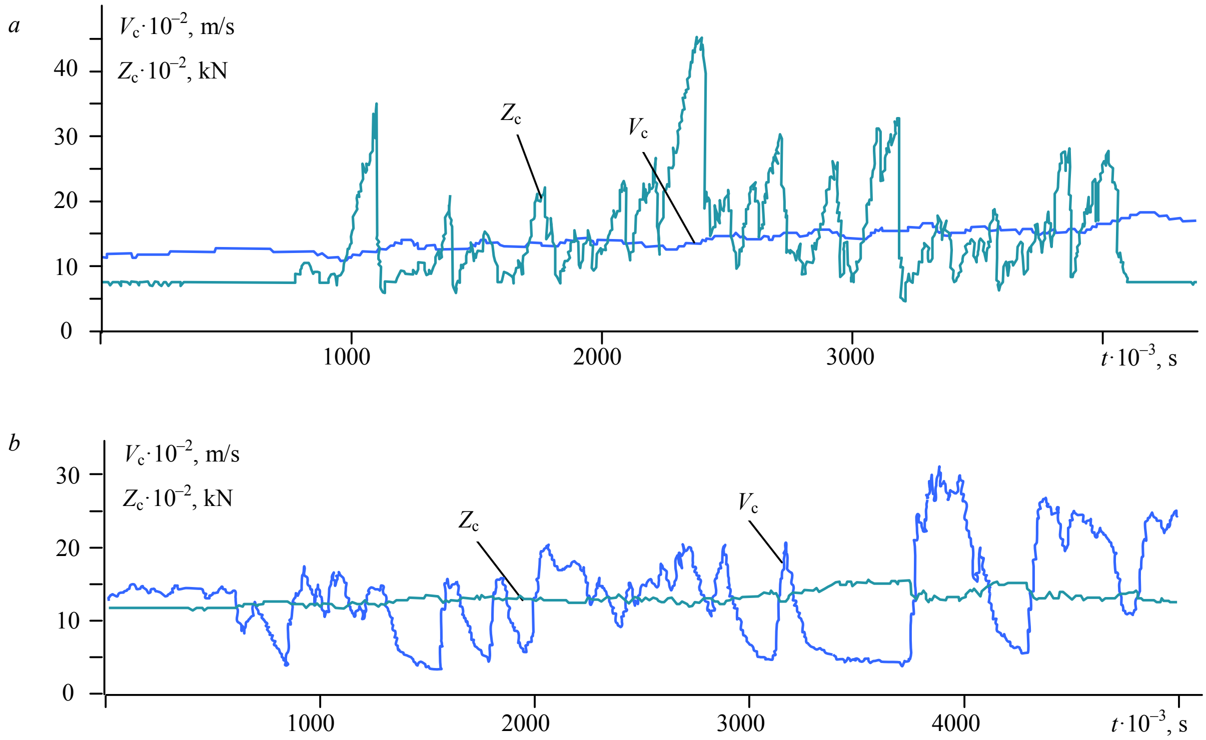

Fig.6. The cutting process with a slotted cut without pneumatic hydraulic accumulators (*a*) and with pneumatic hydraulic accumulators (*b*), cut thickness h = 10 mm

the cutter an acceleration and maintain the critical stress in the fracture field during its growth. With increasing cutting resistance of the rock, the speed of the cutter movement decreases, until it stops completely.

Experiments on a hydraulically driven test bench were carried out when cutting a block of grade Zh coal from the «Moschny» layer, benches n_{14}, n_{13} of the Komsomolskaya mine of OJSC «Vorkutaugol». The average value of the resistance of coal to cutting A = 180 kN/m.

Oscillograms of cutting slotted sections with a sectional shape (h = 10 mm) without pneumatic, hydraulic accumulators (with a constant cutting speed V_c) (Fig.6, *a*) and with pneumatic, hydraulic accumulators (Fig.6, *b*) reflect the fundamental difference in the processes. The first oscillogram confirms the classic nature of the process with a constant cutting speed (V_c = const) and high cutting force dynamics (Z_c), the second – a quasi-constant value of cutting force and high cutting speed dynamics.

The obtained results prove that the propagation velocity of the main crack is close to the velocity of the tool. It should be noted that the frequency of bursting when connecting pneumatic-hydraulic accumulators decreases, and the step t increases, which can favorably affect the reduction of the yield of small classes of coal and dust.

Conclusions

1. High load dynamics on the cutter when cutting coal at a constant speed is not only a consequence of the fragility of the coal but depends on the properties of the cutter drive.

2. By changing the properties of the cutter drive, it is possible to form cutting modes of coal at a constant speed, or with a constant force effect, and intermediate modes according to the variability of speed and cutting forces.

3. The phase-energy approach is promising for the study of the laws governing the process of cutting brittle coals and rocks, in particular for studying the formation of successive elementary bursts and the energy distribution over the phases of an elementary burst.

4. The very possibility of active influence on the shape of the mechanical characteristics of the elementary bursting process has been proved.

5. The results of experimental studies have confirmed the reduction not only of peak cutting forces but also of average loads.

REFERENCES

1. Beron A.I., Pozin E.Z. On the assessment of the energy balance of the process of cutting coal. Tr. IGD im. A.A.Skochinskogo. Podzemnaya razrabotka ugol'nykh plastov. 1972. Iss. 93, p. 10-20 (in Russian).

2. Buyalich G.D., Antonov Yu.A., Sheikin V.I. On the direction of reducing the stress-strain state of the bottomhole zone of a coal seam. Gornyi informatsionno-analiticheskii byulleten'. 2011. Iss. N 2: Gornoe mashinostroenie, p. 198-202 (in Russian).

3. Dokukin A.V., Frolov A.G. Improving coal mining machines based on the kinetic theory of strength. Nauchn. soobshch. IGD im. A.A.Skochinskogo. 1977. Iss. 149, p. 33-41 (in Russian).

4. Gabov V.V., Solov'ev V.S., Zadkov D.A., Kolomoets G.I. The dependence of the maximum cutting forces of brittle fractured coals on the time of the load. *Gornoe oborudovanie i elektromekhanika*. 2006. N 7, p. 37-39 (in Russian).

5. Zagrivnyi E.A., Basin G.G. Formation of the external dynamics of mining machines. *Zapiski Gornogo instituta*. 2016. Vol. 217, p. 140-149 (in Russian).

6. Gabov V.V., Zadkov D.A., Lykov Yu.V., Gurimskii A.I., Shpil'ko S.I. Features of the operation of roadheaders in the mines of OJSC "Vorkutaugol". *Gornoe oborudovanie i elektromekhanika*. 2008. N 12, p. 2-6 (in Russian).

7. Pozin E.Z. The study of the process of destruction of coal by mechanical means in the IHM them. A.A. Skochinsky. *Ugol'*. 1992. N 12, p. 60-62 (in Russian).

8. Pozin E.Z., Melamed V.Z., Ton V.V. Destruction of coal by excavation machines. Moscow: Nedra, 1984, p. 288 (in Russian).

9. Frolov A.G. To the method of solving problems of increasing the output of large classes and reducing dust generation during coal mining. Nauch. soobshch. IGD im. A.A.Skochinskogo. 1972. Iss. 100, p. 152-161 (in Russian).

10. Balaji Aresh. Fundamental Study into the Mechanics of Material Removal in Rock Cutting: Doktoral thesis. University of Northumbria at Newcastle upon Tyne. 2012, p. 169.

11. Buyalich G.D., Buyalich K.G., Umrikhina V.Yu. Study of Falling Roof Vibrations in a Production Face at Roof Support Resistance in the Form of Concentrated Force. IOP Conference Series: Materials Science and Engineering. IOP Publishing. 2016. Vol. 142. P. 012120. DOI:10.1088/1757-899X/142/1/012120.

12. Crosland D., Mitra R., Hagan P. Changes in Acoustic Emissions When Cutting Difference Rock Types. Coal Operators' Conference. University of Wollongong & the Australasian Institute of Mining and Metallurgy. 2009, p. 329-339.

13. Gabov V.V., Lykov Y.V., Bannikov A.A. Analyzing coal breakage while mining at the mines of Vorkuta. International Mining Conference Advanced mining for sustainable development. Halong, 2010, p. 283-285.

14. Gabov V.V., Zadkov D.A. Energy-saving modular units for selective coal cutting. *Eurasian mining*. 2016. N 1, p. 37-40. DOI: 10.17580/em.2016.01.06.

15. Gabov V.V., Zadkov D.A. Peculiarities of stress field formation during cutting isotropic material by mining machine cutters. IOP Conf. Series: Earth and Environmental Science. IPDME. 2017. Vol. 87, p. 022007. DOI:10.1088/1755-1315/87/2/022007.

16. Hua Gua. Rock cutting studies using fracture mechanics principles. Doctor of Philosophy thesis. Department of Civil and Mining Engineering, University of Wollongong, 1990. p. 225.

17. Kazanin O.I., Sidorenko A.A. Interaction between gas dynamic and geomechanical processes in coal mines. *ARPN Journal of Engineering and Applied Sciences*. 2017. Vol. 12. Iss. 5, p. 1458-1462.

18. Khair A.W. Research and Innovations for Continuous Miner's Cutting Head, for Efficient Cutting Process of Rock/Coal. 17 International Mining Congress and Exhibition of Turkey-IMCET 2001, p. 45-55.

19. Shen H.W., Hardy H.R., Khair A.W. Laboratory study of acoustic emission and particle size distribution during rotary cutting. *International Journal of Rock Mechanics and Mining Sciences*. 1997. Vol. 34. Iss. 3-4, p. 121.e1-121.e16. DOI: 10.1016/S1365-1609(97)00247-5.

20. Sidorenko A.A., Sishchuk J.M., Gerasimova I.G. Estimation of methane emission from a longwall panel. *ARPN Journal of Engineering and Applied Sciences*. 2016. Vol. 11. N 7, p. 4448-4454.

21. Wang S., Su J., Hagan P. Energy dissipation characteristics of sandstone cutting under mechanical impact load. *Computer modelling & new technologies*. 2014. 18(3), p. 13-20.

22. Zadkov D., Bolshakov V. Mining machinery: enhancing cutting efficiency. *Russian mining*. 2005. N 1, p. 19-21.

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