IMPROVEMENT OF BLASTING OPERATIONS IN OPEN PIT BY DIFFERENTIAL STRAIN AND SYMMETRICAL BLASTING OF THE ROCK

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Abstract
The purpose of the research is to analyze the patterns of the spatial concentration of explosive energy in a rock massif, which has a complex structure and caused by it the acoustic anisotropy, depending on the design of the borehole charge and the conditions for its blasting; the substantiation of the general approach to the development of technology for the destruction of rock massif under symmetrical effect of the borehole charges. The main factors influencing the impact of the explosion on the quality of the crushing rock under the conditions of application of authored author's decisions regarding the designs of borehole charges, the formation of outcrops, the creation of additional reflective gaps, and vertical ledge of rocks are analyzed in this research. This process of rock destruction with the change of the charge of explosives in the boreholes ranges is considered from the second or third - to the first.
The research methodology includes methods of analytical calculations and geometrical constructions, geomechanical analysis of stressed rock changes in relation to the structural deformities of the ledge of rocks of different heights and lithological composition; substantiation of the simulation model of the propagation of elastic waves in anisotropic crystalline medium and the formation of waveguides in it; static analysis of mine surveyor's observations and mathematical methods for processing the results of experimental and industrial tests. Spatial-mathematical methods of solving problems and comparative assessment of their results are used.
Findings. The peculiarities and conditions of the implementation in iron ore open pit of symmetric blasting of the rock massif with complex regular structure with combined charge of explosives of modern explosives (E) are investigated. The choice of directions` formation in the blast hole network of their location is substantiated. The use of mathematical and simulation modeling, the peculiarities of formation of contours in the rock massif of maximum and minimum stressed zones around borehole charges depending on the physical, mechanical and structural characteristics of rocks as well as relative masses of various types of explosives in the combined charge are determined.
The scientific novelty consists in formulating the author's idea of symmetrical blasting of the rock, differential strain explosion, and analytical substantiation of the parameters of objects and processes for the effective implementation of the developments in the industrial work placement of open pit of ore mining and processing enterprise.
The practical significance of the research is to develop a new effective way of blasting rocks in the open pits of ore mining and processing enterprises and substantiating of the parameters of the technology of the implementation of the method, which reduces the specific costs of explosive materials and increases the profit of the MPE.
Key words: *rock massif, explosive destruction, open pit, explosive waves, anisotropy of rocks, symmetrical action of charge of explosives*

1. Formulation of the problem

Despite the extremely numerous and serious scientific research on the effectiveness of Blasting and Explosion Works (BEW) in the open pits, the problem of the unevenness of the granulometric composition of the blasted rock, as well as the excessively high cost and environmental aggressiveness of this process clearly indicates that this problem is not completely solved. Therefore, the task of the search of the ways to avoid the mentioned negative consequences of the explosion is very relevant, as well as the increase in the effectiveness of the BEW, contributes solving the problem of rational subsurface use, resource and energy saving.

As shown by the analysis of recent studies on the theory of explosion and practice of BEW (Fokin, 2008, Bratanek, 1983), one of the least investigated theoretically and unresolved virtually questions is the

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uneven formation under the action of an explosion of a strained-deformed state of rock masses of a complex regular structure with acoustic anisotropy caused by it , which preferably has a periodic functional dependence (epicycloidal) of elastic-mechanical characteristics relative to the spatial orientation of structural dominants of rocks. The increasing effectiveness of blasting can be possible by differentiating the differential strain of the massif, optimizing the interaction between the borehole charges with the massif and between each other, and also improving the BEW technology, in particular - the methods of creating actually working additional reflective elastic waves of slits and structures of charges for this (Skachkov, 2016). In connection with this, the idea was laid for the use of a preliminary reflection slit for the formation of an additional reflective crack in the acoustically anisotropic rock massif of spatially complex forms of surfaces of various stressed states, as well as the intensification of the differential strain of the massif by explosion at the expense of specially designed multi-type charges E. To solve this problem, the research provided justification for the optimal forms of rock destruction zones around charges of explosives and the mutual arrangement of the mentioned one in the explosive network, when the charges of the first series of the boreholes (main relieving charges) are initiated only after passing through them of the direct and reflected of the slopes of the wave tip the explosion of charges of the second row, thus creating the conditions for the symmetrical action of the basic charges between the two reflective surfaces - the vertical slope of the ledge from one, and created with the short-term "back" gap – from the other.

2. Presentation of research material

It is known that the decrease of the rocks crushing quality with the defined structural-regularity (system cracking and blocking effect) is determined by the formation something like a waveguide due to the refraction and reflection of energy rays from the charge of E in a destructive massif on the contacts of the detached rock, as a result of which different zones of the damaged rock between the blast holes have different granulometric composition, that makes the processors to increase the mass of the explosive in the boreholes for a guaranteed reduction to acceptable levels of the "oversized" exit, at the same time inevitably getting the increased output and the redundant mass. This contradiction led the authors to the idea of finding solutions to avoid this effect by coordinating the combination of the trochoid contours of the destruction zones around the borehole charges of adjacent rows in the presence of vertical ledge of rocks and additional reflecting gaps to provide symmetric conditions work of borehole charges, purposefully designed of a combined construction.

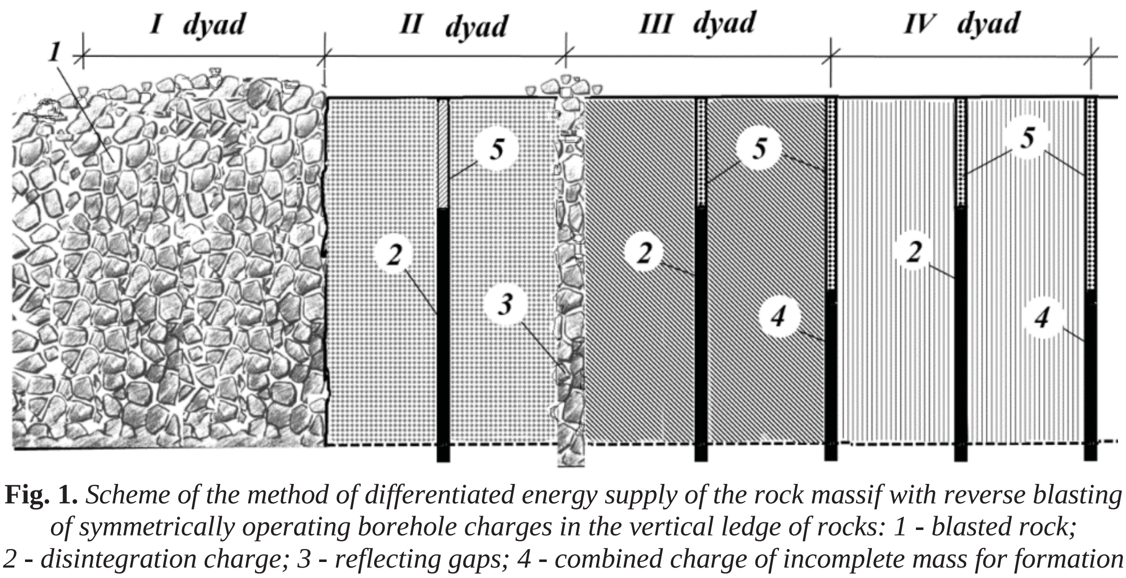

Fig. 1. *Scheme of the method of differentiated energy supply of the rock massif with reverse blasting of symmetrically operating borehole charges in the vertical ledge of rocks: 1 - blasted rock; 2 - disintegration charge; 3 - reflecting gaps; 4 - combined charge of incomplete mass for formation of a reflective gap and preliminary softening of the rock*

At altitudes of ledges up to 10 m, the boreholes are grouped in 2 and undermined with timing from a pair to an odd, that is, in sequence: 2nd→1nd→ 4th→3rd→6th→5th and so on. The application of vertical slopes in combination with the proposed sequence of charges blasting in grouped pairwise rows ensures the unification of borehole charges, and reduces by 5 ÷ 7% the specific cost of E. Under these conditions, a charge protected by a patent was used as the main one (Shapurin, 2016).

The design of the weakened charge - for the preliminary demolition of the breed and the formation of the reflecting gap - was also developed in various variants for different conditions for the implementation of the BEW (Fig. 2).

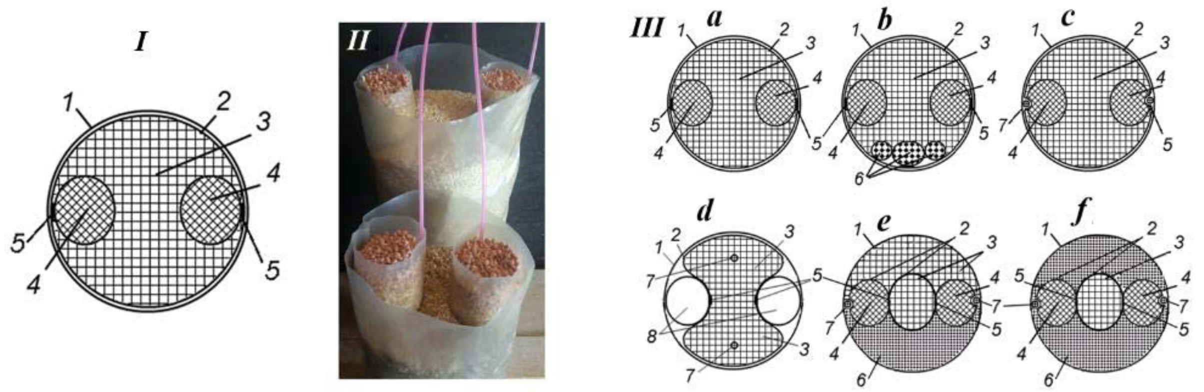

Fig. 2. *Cross section of the borehole charges of the paired rows: 1 - borehole, 2 - polymer shell, 3 - low-brisant charge, 4 - linear high-brisant charges 5 - places of penetration of the sleeve (I); full-scale specimen (II); other variants of charges (III)*

The structures and substances of the main and gaps-forming charges are determined depending on the physical-mechanical characteristics of the rocks, the critical diameters of the E, the ratio of the acoustic rigidity of rock with the detonation velocity of the E, as well as the purpose and requirements for the results of the bursting of the massif.

The analysis of the BHD in relation to the open pit "Pivnichniy", where the mentioned above implementation of the differentiated-energy rocks saturation in the conditions of the dry boreholes with the simplest E - Granulite KM was carried out - showed the following. For this E, the measured values of charge density and detonation velocity are 1020 kg/m3 and 3850 m/s respectively, and the estimated heat of explosion is 980 kcal/kg. Calculated for these conditions, the value of the polytropic index (n) is 1.8, that is within the limits typical for powdered E (1,5 ÷ 2,0). The mass velocity in the Chapman-Jouguet plane (ω, m/s) is calculated by the formula:

$\omega = v/(n+1)$=3850/(1,8+1)=1375 m/s,

and the pressure of the detonation wave on the plane

$P_2 = v\cdot\omega\cdot\Delta/g$=(3850·1020)/9,81=5,504·$10^8$, Pa,

ω = 1020m/s.

This pressure is twice the stationary pressure in the borehole: P_w=5.504·10^8/2 = 2,752·10^8 Pa; Since the charge length is 4 m and its diameter is 0.25 m, the area perceived by this pressure is 3.61 m^2. The total area of the wave from a cylindrical part and two hemispheres from the ends of the charge at the time of its release to the boundary of the crushing funnel is 267.42 m^2, that is in 74 times larger, than the original (3.61 m^2). Taking into account the cost of energy for the rocks destruction (for example, 20%), the pressure is about 3.0 MPa. At the same time, with the approach of the wave to the roof of a ledge, the pressure will be about 0.5 MPa, and near the scarp of a ledge - even less.

At the same time, experimental explosions with the registration of real deformations and stresses in the rock massif around the charges of E revealed somewhat lower indicators than the idealized calculations. Analyzing the stress state and structure of the massif, we established the main cause of this difference - the effect of system macrogaps that divide the rock massif into separate blocks. And after performing a comparative analysis of the values of the above mentioned deviations with the values of the gaps opening, they developed a simplified method of compensating for it in calculations by introducing the corresponding coefficient K_{st}, which differs from the proposed in (Zhukov) in that, it takes into account not only the level of filling gaps with mineral smalls, but also the kinetics of the explosion and the inertial factor of passing an elastic wave through a macrogap. The physical meaning of this coefficient is in the "stepped" cutting of the amplitude of the elastic wave when it is extended through the blocks or layers of the rock (Fig. 3), in combination with plastic deformations of near-surface zones of macrogaps caused by the movement of rock masses when considering the behavior of the collapses rock massif as a set of elastic rods.

Taking into account these factors, we propose to determine this coefficient within the zones of intense explosive loads as,

$$K_g = \sqrt{f\cdot\rho_g}\left(1-\frac{r_{f.w}\cdot g_g}{A}\right)^{(1-\rho_g)} \qquad (1)$$

where f - strength of the breed; ρ_g - the level of filling of the gap by the small rock, is determined by the ratio of the volume of filler V_3 to the volume of the crack $V_g (\rho_g = V_3/V_g)$; $r_{f.w}$ - distance from charge to wave front; g_g - the index of specific fracture of the massif, is determined by the ratio of the average width of systemic gaps, normal with respect to the direction of the waves motion ($g_g = \delta_g/l_g$).

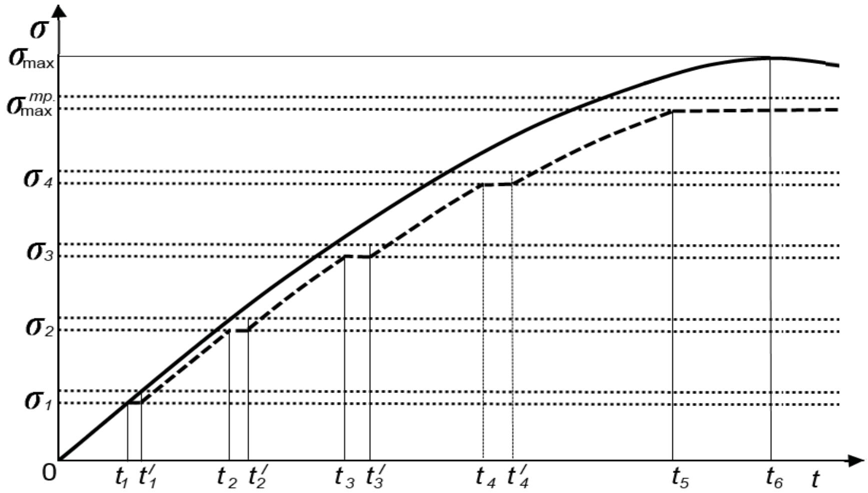

Fig. 3. *Modification of the graph of stress (deformation) dependence at the front of an elastic wave under systemic rock jointing of the rock massif*

Calculated values of K_g for different breeds and structural characteristics of their massifs are shown in Table 1.

Table 1. *Coefficient value K_g*

The name of the rock	Average width of cracks, m	Average distance between cracks, m			
		0,5	1	1,5	2
Granite	0,001	0,96	0,97	0,98	0,99
A_o = 2,5·10^{-2} м,	0,005	0,77	0,89	0,93	0,95
ν = 0,5	0,01	0,45	0,77	0,87	0,89
	0,02	0,01	0,45	0,69	0,77
Migmatites	0,001	0,95	0,97	0,98	0,99
A_o = 2,3·10^{-2} м,	0,005	0,75	0,88	0,91	0,94
ν = 0,5	0,01	0,36	0,75	0,86	0,88
	0,02	0,14	0,36	0,65	0,75
Amphibolitis	0,001	0,94	0,96	0,97	0,98
A_o = 2,1·10^{-2} м,	0,005	0,74	0,87	0,89	0,98
ν = 0,5	0,01	0,22	0,72	0,84	0,81
	0,02	0,10	0,22	0,61	0,72

The introduction of this coefficient significantly improves the convergence of theoretical calculations and experimental records for the determination of the interaction of the energy of the explosion with the rock massif. The calculations of the parameters of the approach to contour blasting, to our opinion, are most convenient to perform in accordance with (Matveichuck, 2002), adding in them the spatial-energy indexes by the developed coefficient K_{st}.

From Fig. 3 it is seen how different theoretical and real, represented by the modified curve, graphs of development of stresses (deformations) at the front of the elastic wave due to the rock jointing system of the rock massif. Accordingly, the boundaries of the zones of minimum and maximum loads of a block rock massif are proposed to be determined not by a theoretical but by a modified trochied.

As for the experimental registrations of the loading levels of rock massif in parallel ($R_\parallel$) and perpendicular ($R_\perp$) of subthorogonal system rock jointing of rocks, they clearly demonstrated how different stress fields are formed, depending on the degree of cleavage of system cracks and caused this acoustic anisotropy of the massif (Fig. 4): in the cemented by the mineral materials of transverse and incompatible closed longitudinal (*a*), which are close by the elasticity to the rock, and "fractured cracks" of both systems (*b*).

The nature of the influence of the structural parameters of the combined charge of E on the relationship between the relative boundaries of the parallel loading zones of the rock massif in parallel ($R_\parallel$) and perpendicular ($R_\perp$) subthorogonal systemic rock jointing from the ratio of masses of high-brisant (M_{hb}) and low-brisant (M_{lb}) charge E (Fig. 6).

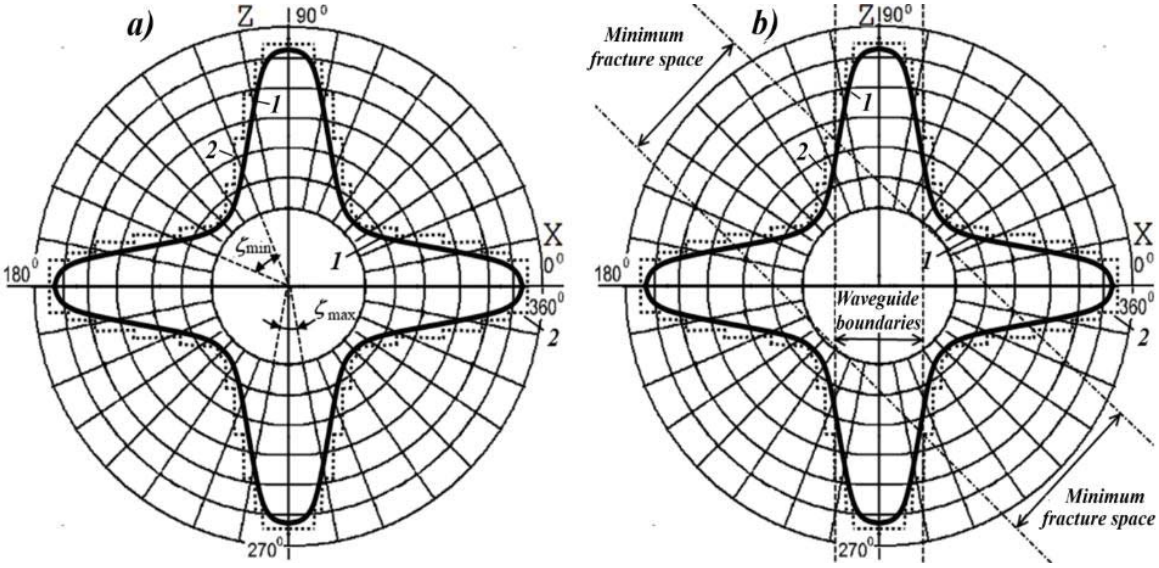

Fig. 4. *Limits zones of optimum and maximum loads of a block rock massif by an explosive wave: 1 – theoretical trochied, 2 – modified trocheid modificat*

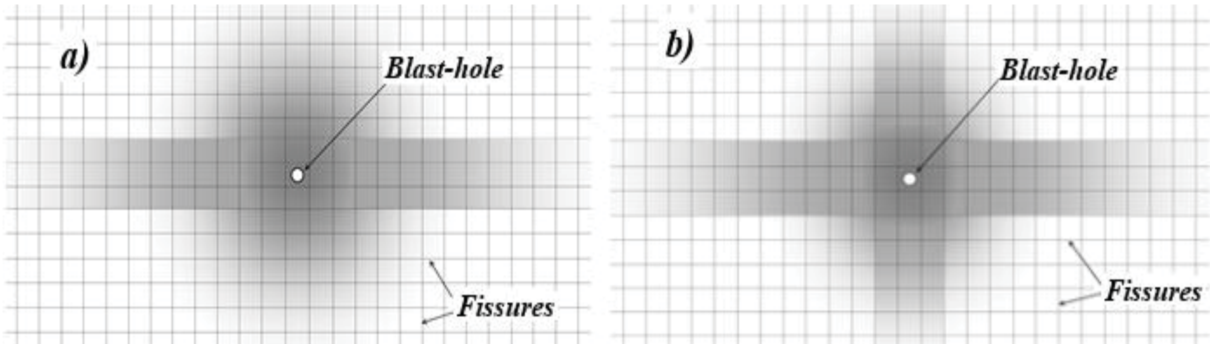

Fig. 5. *The difference between the spatial loading of the rock massif around the borehole charge in dependence on the degree of clustering of systemic gaps*

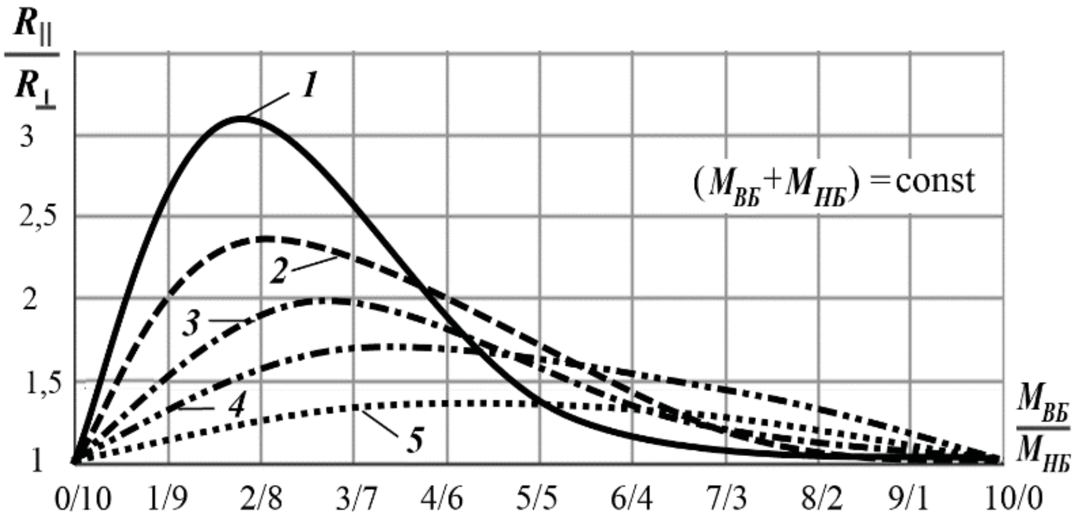

Fig. 6. *Relationship between the relative boundaries of the areas of the equal loading of the rock massif in parallel ($R_{\parallel}$) and perpendicular ($R_{\perp}$) to the subthorogonal systemic rock jointing from the ratio of masses of high-brisant (M_{hb}) and low-brisant (M_{lb}) charge.*

3. Conclusions

The described above facts convince that for the ledges up to 11 m, the division of rows into groups, two in each, a significant reduction in the mass of charges in dual rows, the division of charges in the group into separate series and the beginning of the initiation of each series, namely, from the reduced by weight of charges, forcing these reduced charges give all the energy to the formation of a shielding gap, the development of defective rock of microcracks, the formation of reflected waves from free surfaces, overcoming the inertia of the massif, that is together makes easier the work of crushing rocks with the main charges in odd rows, decreasing the overall cost of E and, consequently, increases the effectiveness of E charges.

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