УДК 622.235 DOI: 10.21440/0536-1028-2019-6-5-13

Investigating the parameters of dispersion in the plane system of charges at granular quartz deep mining

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Abstract

Introduction. *There is much concern about raw material overgrinding as a result of blasting when mining granular quartz. The main blasting method of deep mining is borehole blasting with rings of continuous charges. The main drawbacks of the method include nonuniform distribution of explosives along the plane of the broken layer and the fact that the significant energy of continuous charges is spent on the shattering effect which automatically overgrinds the material in the area nearest the blast.*
Research aim *is to develop the technology of blasting and optimize its parameters ensuring the reduced output of overgrinded quartz fraction.*
Methodology *includes the development and application of a mathematical model of drilling and blasting parameters forecast in granular quartz deep mining.*
Research concept. *A technology of breaking has been proposed by way of solution to the given problem. The technology lies in the concept that the uniformity of explosive energy concentration distribution in the broken layer is ensured by charges dispersion by air gaps and the particular order of their arrangement in the plane of the ring. To implement the technology, a method of forming dispersed charges in deep upholes has been developed; the method does not require additional efforts and equipment.*
Results. *A special technique has been created, which makes it possible to determine the parameters of dispersion ensuring the relevant specific consumption of explosives along the whole plane of the broken layer. The dependence between the output of the overgrinded quartz fraction and the parameters of dispersion in the plane system of charges has been determined. Engineering and economic evaluation of breaking technology options has been carried out as compared to the conventional one. Potential economic benefit has been estimated from the developed technology application for 1t of produced ore.*

Key words: *granular quartz; blasting; dispersed charge; borehole ring; air gap; specific consumption of explosives.*

Introduction. Qualitatively unique granular quartz of the Southern Ural Kyshtym deposit is used to produce high-purity quartz concentrates which are in demand in high-technology industry. It is a very hard material consisting of poorly connected grains (granules) as large as 1–2 mm, which is conditioned by their rather smooth and even edges [1, 2]. Due to this structural feature, an output of overgrinded fraction is high when drilling and blasting at stoping. According to raw material quality specifications, 0–20 mm quartz fraction, which is sorted out at the surface and piled, is unfit for high-purity quartz production, whereas its output reaches 20% [3].

Traditionally, breaking was carried out by the charges of cartridged explosives dispersed by nonreactive aggregate in rings of boreholes 105 mm in diameter and 10 m in length. Specific consumption of explosives was 0.9–1.0 kg/m^3. The charge of each borehole was fired with a delay, i. e. acted as an individual one [4]; it caused significant detonation power input to break rock in camouflet zone [5, 6]. When moving forward to the next level, the mining method changed [3], cameral deposits breaking being carried out by the rings of upholes as long as 24 m. In order to reduce quartz overgrinding in the area nearest the blast, the use of a plane system of charges was proved [7], involving simultaneous blasting of all charges in a ring with the arrangement parameters ensuring their interaction [8]. Besides, in order to reduce the shattering effect at the initial stage of detonation, it is sensible to use charges with air gaps [9–13]. For the conditions of upholes and pneumatic charging with granular explosives, the method of forming such charges was developed [14].

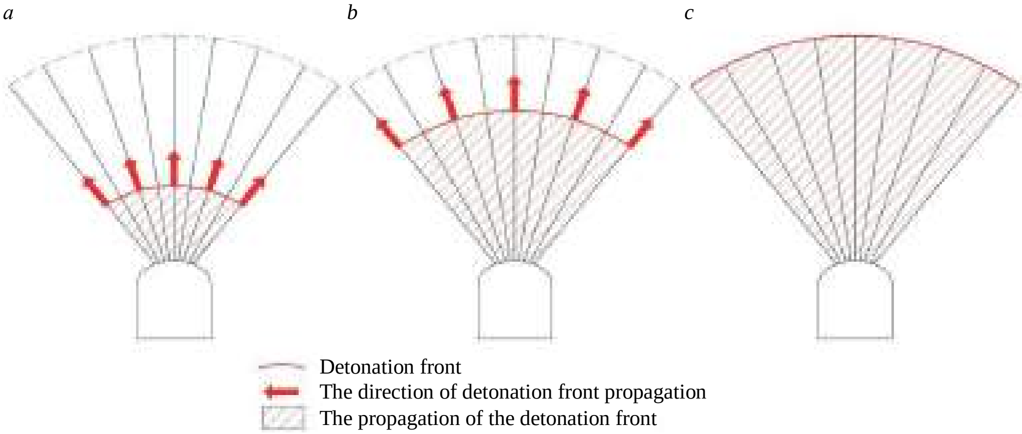

Fig. 1. Propagation of the detonation front in the plane of blast hole ring:
at the initial stage – *a*; at an intermediate stage – *b*; at the final stage – *c*
Рис. 1. Распространение детонационного фронта в плоскости веера:
на начальном этапе – *a*; на промежуточном этапе – *b*; на завершающем этапе – *c*

Thus, it is necessary to develop a procedure which will make it possible to determine the parameters of spatial arrangement of explosive charges and air gaps in the broken massif. It is a crucial scientific engineering task.

The principles of charges dispersion parameters determination. The following principles are at the heart of the developed procedure of dispersion parameters calculation:

– the parameters of boreholes arrangement at the ring scheme of breaking, required to completely separate a layer from the massif and get the necessary quality of ore breaking, are calculated for the zone of the faces of wells; as far as the remaining part of the broken layer is concerned, specific consumption of explosives is controlled by means of dispersing the charges;

– simultaneous initiation of all charges is designed;

– codirectional propagation of detonation of all borehole charges; with the simultaneous detonation procedure, the direction of detonation propagation depends on the arrangement of priming cartridges (booster charges) in boreholes [15, 16]; with dispersed charges, booster detonator is placed in each individual part of a charge.

The schematic spatial-temporal diagram of detonation front propagation is presented at fig. 1.

The detonation front can be pictured as an arch, and its propagation, if conditionally broken into time segments, can be pictured as arcuate zones filling. Summarizing the above, it can be concluded that in order to calculate the parameters of charges dispersion, it is reasonable to divide the plane of the ring into the arcuate zones, within the limit of each arcuate zone the specific consumption of explosives will be about the same.

Definition and systematization of mine and technical factors. For the good of the developed procedure, it is necessary to systematize the main mine technical factors affecting the parameters of charges dispersion in a ring. As a result, the following mine technical factors were determined and divided into two groups: volume factors, i. e. determining the volume of the broken massif, and power factors, i. e. affecting the parameters of its power ratio (table 1).

Mine technical factors

Volume factors

The volume of the broken layer .... V_l, m^3
The line of least resistance .... W, m
Borehole length .... L_{bhl}, m
The span angle between the marginal boreholes of the ring .... α, degrees

Power factors

Specific consumption of explosives .... q_{expl}, kg/m^3
Boreholes contingency coefficient .... m, items
The number of boreholes in a ring .... n_{bhl}, items
Borehole diameter .... d_{bhl}, m
Charging density .... ρ_{char}, kg/m^3

The main volume factor is the volume of the broken layer and the main power factor is the specific consumption of explosives. However, both groups are interconnected as soon as each factor in some way influences the parameters of the other. Consequently, the developed procedure has to consider the given factors together and ensure uniform distribution of explosives in each section of the broken layer, in this case – in each arcuate zone.

Table 1. Parameters and indicators of experimental explosions of a plane system of charges
Таблица 1. Параметры и показатели проведения экспериментальных взрывов плоской системой зарядов

Explosion no.	Charges structure	q_{expl}, kg/m^3	d_{bhl}, mm	W, m	a, m	m	γ_{0-20}, %
1	Continuous	1.5	65	1.6	2.2	1.4	25.3
2	Dispersed	1.2	65	1.6	2.2	1.4	20.6
3	Dispersed	1.0	65	1.7	2.4	1.4	12.0
4	Dispersed	0.9	65	1.6	2.2	1.4	19.3
5	Dispersed	0.9	65	1.8	2.2	1.2	12.2

a – the distance between the edges of the boreholes.

Developing the procedure of dispersion parameters calculation. In simultaneous detonation of ring charges, the detonation front can be represented as an arch, and its propagation, if conditionally broken into time segments, can be pictured as arcuate zones filling. Consequently, in order to calculate the parameters of charges dispersion, it is reasonable to divide the plane of the ring into the arcuate zones, within the limit of each arcuate zone the specific consumption of explosives will be about the same. The lengths of the sectors of charges and air gaps in the adjoining boreholes will be equal to the height of the i-th arcuate zone.

The ring of boreholes is represented in an idealized form as a sector of a circle with a centre in a drilling room O, radius equal to the length of boreholes L, and span angle α between the marginal boreholes of the ring (fig. 2).

Specific consumption of explosives for each *i*-th arcuate zone q^i_{char} is expressed through the main mine technical parameters

$$q^i_{\text{expl}} = \frac{n_{\text{bhl}}(l_{i\text{u}} - l_{i\text{l}})\pi d^2 4^{-1}\rho_{\text{char}}}{W\pi \frac{\alpha}{360}(l_{i\text{u}}^2 - l_{i\text{l}}^2)}, \tag{1}$$

where $i = 1, ..., m$ – the number of arcuate zones in a ring, items; n_{bhl} – the number of boreholes in a ring, items; $l_{i\text{u}}$ – length from the ring centre (drill rig axis) to the upper border of the *i*-th arcuate zone, m; $l_{i\text{l}}$ – length from the ring centre to the lower border of the *i*-th arcuate zone, m; d – borehole diameter, m; ρ_{char} – charging density, kg/m^3; W – the line of least resistance (LLR), m.

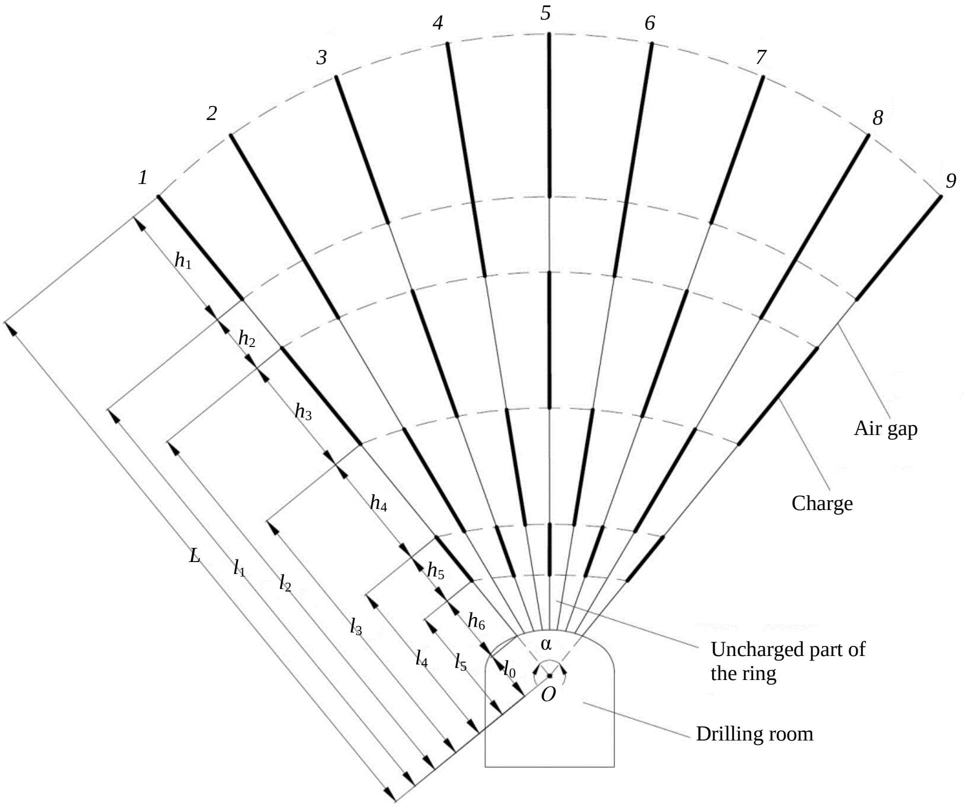

Fig. 2. Schematic diagram of dispersion parameters determination in the plane system of charges
Рис. 2. Принципиальная схема для определения параметров рассредоточения в плоской системе зарядов

The heights of the arcuate zones in generally are determined by the formula

$$h_i = l_{i\text{u}} - l_{i\text{l}}. \tag{2}$$

Having expressed $l_{i\text{l}}$ with equation (1), we get

$$l_{i\text{l}} = \frac{90 n_{\text{bhl}} d^2 \rho_{\text{char}}}{W\alpha q_{\text{expl}}} - l_{i\text{u}}. \tag{3}$$

Successive solution of equation (3) for arcuate zones, moving from the face to the top of wells, makes it possible to determine the desired parameters of dispersion.

Dispersion parameters study. In the in situ conditions of Kyshtym underground mine, field studies of granular quartz breaking have been carried out. The main experimental parameters and 0–20 mm (γ_{0-20}) fractions yield are presented in table 1.

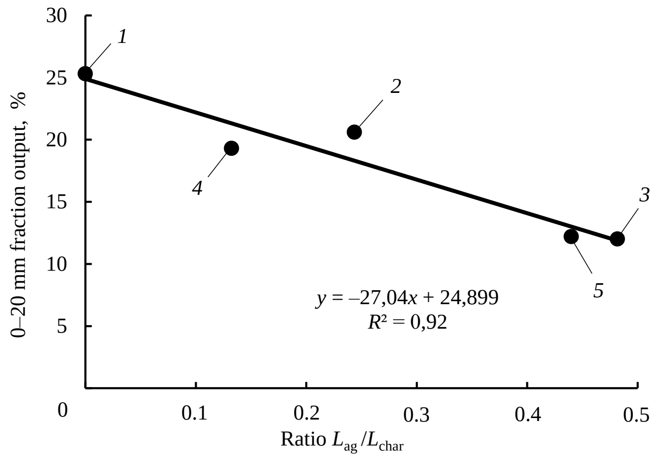

Fig. 3. Dependence between 0–20 mm fraction output and the dispersion parameters in a plane system of charges

Рис. 3. Зависимость выхода фракции 0–20 мм от параметров рассредоточения в плоской системе зарядов

Evident spread of results of two explosions (no. 4 and no. 5) with similar specific consumption of explosives has shown that the dispersion itself does not guarantee the required quality of quartz ore breaking.

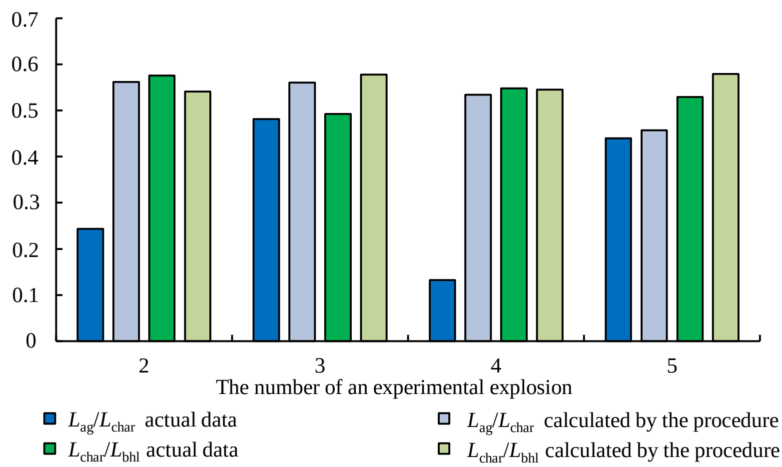

Fig. 4. Comparison of actual and calculated parameters of experimental explosions of a plane system of dispersed charges

Рис. 4. Сопоставление фактических и расчетных параметров экспериментальных взрывов плоской системы зарядов рассредоточенной конструкции

For that matter, the influence of process parameters, i. e. the ratio of the sum of the length of air gaps L_{ag} to the sum of the lengths of explosives L_{char} in a ring, on the output of the overgrinded fraction was studied. The actual parameters at experimental blast were measured. As a result, the dependence between the output of 0–20 mm quartz fractions and L_{ag}/L_{char} (fig. 3) was established; it is approximated by the formula

$$\gamma_{0-20} = -27{,}04 L_{ag} / L_{char} + 24{,}899. \quad (4)$$

It can be seen from the diagram that with the increase of L_{ag}/L_{char} from 0 to 0.48, the output of 0–20 mm fraction reduces from 25.3% to 12%. For the conditions of Kyshtym underground mine, optimum are the values ranging within L_{ag}/L_{char} = 0.44–0.48, allowing to reach layer separation from the massif with minimum output of the oversized fraction.

Table 2. Technical and economic evaluation of blasting technology options
Таблица 2. Технико-экономическая оценка по вариантам технологии отбойки

Indicator	Blasting technology option				
	Conven-tional	1	2	3	4
The line of least resistance, m	2.5	2.5	2.5	1.7	1.8
Boreholes contingency coefficient, items	1.0	1.3	1.3	1.2	1.2
Specific consumption of explosives, kg/m^3	0.9	1.7	1.4	1.2	0.9
Flow rate, m/m^3	0.29	0.28	0.28	0.73	0.43
Borehole length in a ring, m	86	160	162	295	188
Borehole number in a ring, items	14	9	9	15	11
Oversize output, %	10.0	2.0	2.5	10.0	7.6
The cost of 1 m^3 oversize breaking, rub/m^3	500				
0–20 mm fraction output, %	20.0	35.6	25.7	17.1	12.2
The price of 1t of preconcentrate, rub/t	3500				
The prime cost of breaking, rub/t	106.4	120.0	116.9	162.6	104.4
The prime cost of oversize breaking, rub/t	18.87	3.77	4.72	18.87	14.34
Economic benefit for 1t of produced ore, rub/t	0	–190.07	–68.34	+17.05	+97.61

Actual parameters of two best blasts converge with the values calculated by (1)–(3): for blast no. 3 they are 0.48 and 0.56 (Δ_3 = 14.2%), for blast no. 5 – 0.44 and 0.46 (Δ_5 = 4.3%). For blasts no. 2 and no. 4, significant divergence between actual and theoretical parameters (Δ_2 = 57.1% and Δ_4 = 75.4%) can be explained by the irrational undercharge of boreholes [17]. It is proved by the adequate convergence of actual and computational ratios of the sum of charge lengths with the sum of boreholes lengths (Δ = 0.5–15.5%) (fig. 4). This degree of convergence testifies to the adequacy of the developed procedure.

In research [18] V. N. Mosinets notes that when breaking ore, condition $L_{ag}/L_{char} \le 0.44$ is preferable, and the highest coefficient of explosion energy transfer to the environment is observed with L_{ag}/L_{char}= 0.3. When breaking granular quartz, it is also necessary to minimize the effect on the broken layer. Taking into account the indicators of ore quality, it can be assumed that for the conditions of Kyshtym underground mine, expression $L_{ag}/L_{char} \ge 0.44$ will be true.

Engineering and economic evaluation of technology options has been carried out according to the criterion of maximum economic benefit, as compared to the conventional one (table 2). The benefit has been determined at the stage of preconcentrate with 90% of quartz. Four options of the technology have been studied:

1. Continuous charges, d_{bhl} = 105 mm;
2. Dispersed charges, d_{bhl} = 105 mm;
3. Continuous charges, d_{bhl} = 65 mm;
4. Dispersed charges, d_{bhl} = 65 mm.

The fourth option has best estimators; it applies a plane charge system of dispersed structure in 65 mm diameter boreholes with the parameters established in the course of the research. The main factor affecting the economic effectiveness is the output of the oversized 0–20 mm fraction. Potential economic benefit from the implementation of the developed option for 1t of produced ore is 97.6 rub.

Conclusion. The procedure of charge dispersion parameters calculation has been developed, wherein the features and the parameters of blasting technology with the ring arrangement of boreholes and simultaneous method of blasting are taken into account. The dependence has been established between the output of the overgrinded quartz fraction and the ratio of the lengths of the dispersed charge elements. Overgrinded quartz fraction output reduction by 25–40%, as compared to the conventional blasting technology, is reached by the use of the plane charge system of dispersed structure with specific consumption of explosives 0.9–1.0 kg/m^3 and the ratio of the lengths of air gaps to the lengths of the explosive charges 0.44–0.48.

Research has been carried out under the government contract no. 075-00581-19-00. Theme no. 0405-2019-0005.

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Received 7 May 2019

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DOI: 10.21440/0536-1028-2019-6-5-13

Исследование параметров рассредоточения в плоской системе зарядов при подземной добыче гранулированного кварца

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Реферат
Введение. *При добыче гранулированного кварца остро стоит проблема переизмельчения сырья в результате взрывных работ. При подземной разработке основным способом ведения взрывных работ является скважинная отбойка веерами зарядов сплошной конструкции. Основные недостатки способа – неравномерность распределения взрывчатого вещества по плоскости отбиваемого слоя и расходование значительной части энергии зарядов сплошной конструкции на бризантное воздействие, обязательно связанное с переизмельчением материала в ближней зоне взрыва.*
Цель работы. *Разработка технологии взрывной отбойки и оптимизация ее параметров, обеспечивающих снижение выхода переизмельченной фракции кварца.*
Методология. *Разработка и использование математической модели прогноза параметров буровзрывных работ при подземной добыче гранулированного кварца.*
Идея работы. *В качестве решения данной проблемы предложена технология отбойки, заключающаяся в том, что равномерность распределения концентрации энергии ВВ в отбиваемом слое обеспечивается за счет рассредоточения зарядов воздушными промежутками и определенного порядка их размещения в плоскости веера. Для практической реализации технологии разработан способ формирования рассредоточенных зарядов в восстающих глубоких скважинах, не требующий дополнительных трудозатрат и специальных средств.*
Результаты. *Создана специальная методика, позволяющая определить параметры рассредоточения, обеспечивающие необходимый удельный расход ВВ по всей плоскости отбиваемого слоя. Установлена зависимость выхода переизмельченной фракции кварца от параметров рассредоточения в плоской системе зарядов. Проведена технико-экономическая оценка вариантов технологии отбойки относительно традиционной. Определен потенциальный экономический эффект от применения разработанной технологии на 1 т добытой руды.*

Ключевые слова: *гранулированный кварц; взрывная отбойка; рассредоточенный заряд; веер скважин; воздушный промежуток; удельный расход ВВ.*

Исследования выполнены в рамках Госзадания № 075-00581-19-00. Тема № 0405-2019-0005.

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Поступила в редакцию 7 мая 2019 года

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Для цитирования: Соколов И. В., Рожков А. А. Исследование параметров рассредоточения в плоской системе зарядов при подземной добыче гранулированного кварца // Известия вузов. Горный журнал. 2019. № 6. С. 5–13 (In Eng.). DOI: 10.21440/0536-1028-2019-6-5-13
For citation: Sokolov I. V., Rozhkov A. A. Investigating the parameters of dispersion in the plane system of charges at granular quartz deep mining. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal Gornyi zhurnal = Mining Journal*. 2019; 6: 5–13. DOI: 10.21440/0536-1028-2019-6-5-13