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IMPROVEMENT OF THE SYSTEM OF EXPLOSIONS OF RING HOLES DURING THE DEVELOPMENT OF LOW-POWER ORE DEPOSITS

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Abstract. Due to the depletion of powerful rich mineral deposits and, accordingly, the transition to the development of low-power ore deposits with a lower content of the useful component, it is possible to increase the efficiency of underground mining by improving individual processes of the most effective development systems that reduce the cost of production with high recovery rates. One of the most common systems for the development of low-power ore deposits is the system of sub-level caving mining, which is widely used both at domestic and foreign underground mines. Improving the efficiency of one of the main processes of this system, which consists in carrying out drilling and blasting operations by improving fragmentation indicators and improving blasting schemes, which can provide higher rates of excavation of rock mass and, consequently, reducing the cost of loading, transportation and increasing the service life of the main nodes and components of loading and unloading and transport equipment. In relation to the conditions of the polymetallic deposit of the Strezhansky mine, studies were carried out on the factors of single blasting separation (SBS) of wells into two parts in a sublevel collapse with the establishment of a rational value of sequential deceleration. It is theoretically justified and experimentally confirmed that the improved SBS method gives higher crushing rates and an increase in mineral extraction in addition to reducing vibration and rock impacts. Analysis of the results of experimental studies allows us to formulate a conclusion that when using an improved method of blasting wells, the percentage of mineral extraction increases by 5-10% compared to existing blasting methods.
Keywords: ore mining, sub-level caving mining, frontal discharge, disturbed flow, ore loss, dilution

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АЗ ҚУАТТЫ КЕН ОРЫНДАРЫН ИГЕРУ КЕЗІНДЕ ТАРАМДАЙ САНЫЛАУЛАРДЫН ЖАРЫЛУ ЖҮЙЕСІН ЖЕТІЛДІРУ

Аннотация. Пайдалы қазбалардың қуатты бай кен орындарының сарқылуына және, тиісінше, пайдалы құрамдас бөлігі аз қуатты кен орындарын игеруге көшуіне байланысты, пайдалы қазбалардың жерасты өндірісінің тиімділігін өндірудің жоғары көрсеткіштері кезінде өндірудің өзіндік құнын төмендетуді қамтамасыз ететін, неғұрлым тиімді игеру жүйелерінің жекелеген процестерін жетілдіру арқылы арттыруға болады. Аз қуатты кен орындарын игерудің ең көп таралған жүйелерінің бірі-отандық және шетелдік жер асты кен орындарында кеңінен қолданылатын қабатты құлау жүйесі. Бұл жүйенің негізгі процестерінің бірінің тиімділігін арттыру, бұл тау жыныстарын алудың жоғары қарқынын қамтамасыз ете алатын жарылыс сызбаларын жақсарту және жетілдіру арқылы бұрғылау-жару жұмыстарын жүргізу, демек, тиеу, тасымалдау шығындарын азайту және тиеу-түсіру және тасымалдау жабдықтарының негізгі компоненттері мен компоненттерінің қызмет ету мерзімін арттыру болып табылады. Стрежан кенішінің полиметалл кен орнының жағдайларына қатысты бірізді баяулаудың ұтымды шамасын белгілей отырып, деңгейлік опырылыста ұңғымалардың жеке жарылуын (орларын) екі бөлікке бөлу факторларына зерттеулер жүргізілді. Жетілдірілген арық әдісі діріл мен тау соққыларын төмендетумен қатар, ұсақтаудың жоғарылауын және минералды өндірудің жоғарылауын беретіні теориялық тұрғыдан негізделген және эксперименталды түрде расталған. Эксперименттік зерттеулердің нәтижелерін талдау ұңғыманы жарудың жетілдірілген әдісін қолданған кезде пайдалы қазбаларды алу пайызы қолданыстағы жару әдістерімен салыстырғанда 5–10 %-ға артады.

Түйін сөздер: кенді өндіру, қабаттық құлату, сыртын шығару, бұзылған ағым, кен шығыны, құнарсыздану

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СОВЕРШЕНСТВОВАНИЕ СИСТЕМЫ ВЗРЫВОВ ВЕЕРНЫХ СКВАЖИН ПРИ ОТРАБОТКЕ МАЛОМОЩНЫХ РУДНЫХ ЗАЛЕЖЕЙ

Аннотация. В связи с истощением мощных богатых месторождений полезных ископаемых и соответственно переходом к разработке маломощных рудных залежей с более низким содержанием полезного компонента, повысить эффективность подземной добычи полезных ископаемых можно за счет совершенствования отдельных процессов наиболее эффективных систем разработки, обеспечивающих снижение себестоимости добычи при высоких показателях извлечения. Одной из наиболее распространенных систем разработки маломощных рудных залежей является система подэтажного обрушения, которая широко используется как на отечественных, так и зарубежных подземных рудниках. Повышение эффективности одного из основных процессов этой системы, заключающегося в проведении буровзрывных работ за счет улучшения показателей фрагментации и совершенствования схем взрывных работ, которые могут обеспечить более высокие темпы выемки горной массы и, следовательно, снижение затрат на погрузку, транспортировку и увеличение срока службы основных узлов и компонентов погрузочно-разгрузочного и транспортного оборудования. Применительно к условиям полиметаллического месторождения Стрежанского рудника были проведены исследования факторов разделения одиночного взрывания (РОВ) скважин на две части в подуровневом обрушении с установлением рациональной величины последовательного замедления. Теоретически обосновано и экспериментально подтверждено, что усовершенствованный метод РОВ дает более высокие показатели дробления и увеличение извлечения полезного ископаемого помимо снижения вибрации и горных ударов. Анализ результатов экспериментальных исследований позволяет сформулировать вывод о том, что при использовании усовершенствованного метода взрывания скважин РОВ процент извлечения полезного ископаемого повышается на 5–10 % по сравнению с существующими методами взрывания.

Ключевые слова: добыча руд, подэтажное обрушение, торцовый выпуск, нарушенное течение, потери руды, разубоживание

Introduction

During the underground mining of low-power ore deposits using the system of sublevel caving mining (SLC) (Ganqiang et al., 2019: 50), it was found that it has many advantages in terms of safety and the level of mechanization. Due to this advantage over others, it has become widely used in mining at various mines around the world for many years. With such a system, the block being worked out is divided into sub-stages, and the sub-stages are worked out in descending order with diamond-shaped panels. The ore massif is drilled with vertical or steeply inclined fans of ascending wells along the entire length of the panel of orts. Currently, the SLC is also used in coal mines. (Wang et al., 2016: 12).

However, the SLC has certain disadvantages, such as (Shuai Xu et al., 2017: 63):
– instability of extraction indicators;
– relatively low technical and economic indicators;
– significant ore losses and dilution.

Ore losses in the mining process, which reach up to 20 %, are not uncommon for SLC (Zhang, 2016). In addition, it is recognized that blasting plays a very important role not only in the extraction, but also in the crushing of rock mass (Adrianus, 2006).

Quantitative assessment of fragmentation of rock mass as a result of explosion is useful in assessing the effectiveness of drilling and blasting operations (DBO) in order to determine the actual destruction of rock mass by explosion to a size acceptable for loading operations and not exceeding the diameter of the receiving part of the crusher. Improving the fragmentation parameters and ensuring the uniformity of fragmentation throughout the DBO profile can provide higher rates of excavation of rock mass (Varcoe, 2019) and, consequently, reduce the cost of loading, transportation and increase the service life of the main components and components of loading and unloading, transport and crushing equipment.

Thus, it is important for the SLC to improve the indicators of fragmentation and extraction of minerals by improving the schemes of blasting operations. (Volkov et al., 2018)

A significant indicator of what can have a negative impact on the stationarity of the ore crushing process is its uncontrolled crushing during explosive breaking and, as a result, the appearance of oversized rocks in the produced rock mass (DeCagné et al., 2005).

Like other methods of underground mining, SLC faces serious problems such as seismic events and rock impacts with increasing mining depth. More and more studies show that many seismic events and rock impacts initiated by explosions, especially massive ones (Eremenko et al., 2009: 6) indicate that the total amount of explosive at each deceleration time should be reduced, however, this is a dilemma for mining operations. To reduce the amount of explosive in one deceleration, it is necessary to use more wells of smaller diameter, or short wells of smaller diameter to replace long wells of larger diameter. If this is the case, then drilling and development costs should be increased because more blast wells need to be drilled or the production system needs to be improved to maintain a constant scale of production. Obviously, this is not the best way (Volkov et al., 2019: 4).

Based on the results of the analysis of previously performed studies, it was found that if a long well is divided into two parts, and they will be blown up with two different time decelerations long enough to avoid overlapping voltage waves from both parts, then the amount of explosive at each moment of delay can be reduced. This idea underlies the method of dividing a single blasting separation (SBS) into two parts in a sublevel collapse. The SBS method was originally developed to reduce seismic vibrations at the Malmberget mine in Sweden (Zhang et al., 2005: 17).

When the SBS method was initially applied to wells at the Malmberget mine in order to reduce rock impacts, it was unexpectedly found that this method gives higher percentages of crushing and ore extraction in addition to reducing vibration and rock impacts (Zhang, 2012: 9).

In connection with this positive result, the improved SBS method, by choosing rational deceleration intervals, was tested at the Strezhansky polymetallic ore deposit owned by "Ridder Polymetal" LLP, located in east Kazakhstan. Ore bodies of the Strezhansky deposit are low-power from 1 to 7 meters (Lisenkov et al., 2016: 4).

Research materials and methods

In the drift No. 033 and No. 34 (at the Strezhansky mine) with electronic detonators, 18 drill rings were blown up, nine drill rings by the standard method Fig. 1 A, then nine drill rings by the SBS method, Fig. 1 B, after which a comparison was made on the percentage of extraction, granulometric composition of the beaten ore, as well as weighing of an underground dump truck with a payload.

In drift No. 033, with the standard method of conducting explosions in drill rings № 1–09, the delay time between wells was 100 ms. The diameter of the wells is 105 mm.

In drift No. 034, with the method of conducting SBS explosions in drill rings № 10–19, the delay time in the bottom part of the drill ring was 12 ms, and in the estuarine – 70 ms. The diameter of the wells is 85 mm.

Fig. 1 shows the locations of holes rings with two methods of blasting ring holes. With a large spread in the response time of downhole detonators, in order to achieve the minimum seismic impact of a mass explosion, the deceleration intervals in downhole detonators were chosen longer than the time of their response spread (Zhang et al., 2018: 9).

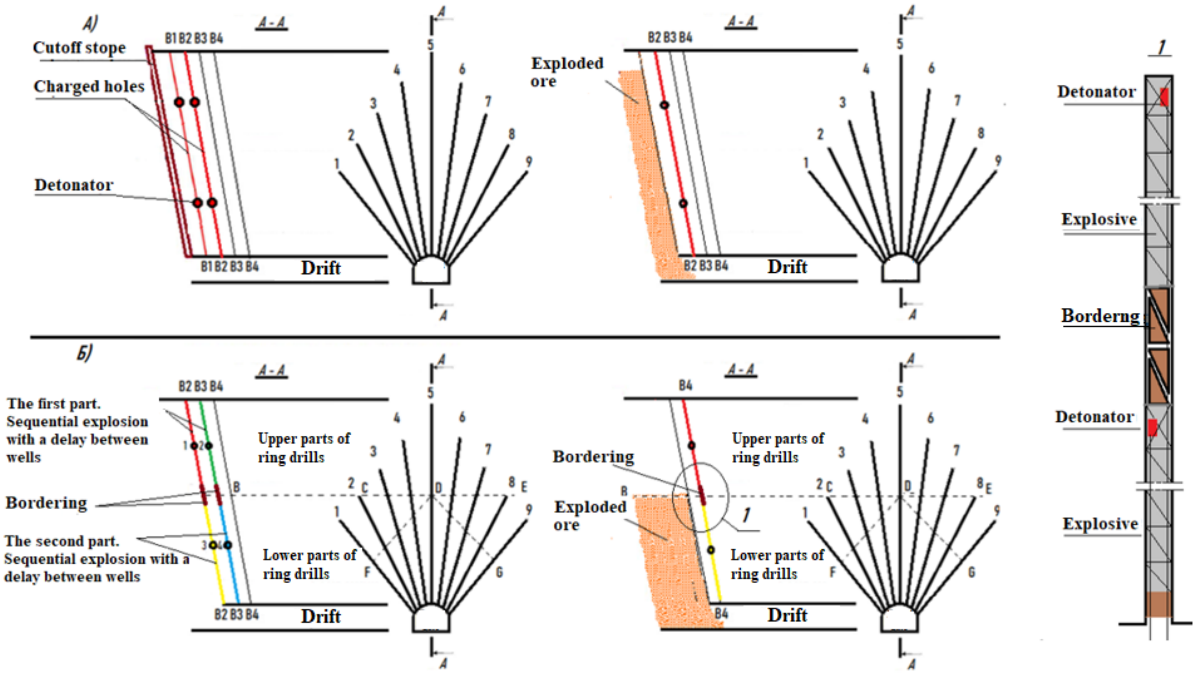

Figure 1. Methods of blasting ring holes:
(A) – the standard method of blasting; (B) - an improved method of SBS blasting.
Scheme of the SBS method. The dotted BCDE line represents the middle line of the drill ring. Each drill ring of SBS is divided into two equal parts by a dotted line FDG.

With the standard method of conducting explosions of a low-power ore body in the drift No. 033 Fig. 1 (A), pre-charged ring holes B1 and B2 explode sequentially with deceleration. After the explosion, the re-captured rock mass near the cutting gap is unloaded. Then the whole process is repeated for the remaining ring holes.

The extraction percentage for all drill rings in drift № 033 is shown in Fig. 2 in blue, which indicates that the average percentage of ore extraction with the standard method is 64 %.

There are several ways to eliminate the low percentage of ore extraction with the standard method of explosions in comparison with the advanced one (SBS). The main ones are (Shekhara et al., 2020: 8):

– optimization of methods (DBO);
– reducing the diameter of drilling wells with an increase in their number;
– application of advanced drilling schemes, including contour blasting;
– use of guide rods (to reduce well deflection);
– development of an improved technological process in order to optimize the DBO scheme and reduce dilution.

The SBS method was tested experimentally in a low-power ore body in the drift № 034 Fig. 1 (C). The pre-charged bottom parts (1,2) of the drill rings B2 and B3 explode with deceleration sequentially, and the wellhead part (3,4) of the drill holes B2 and B3 also pre-charged with explosives explodes after the explosion of the bottom parts with deceleration sequentially.

A method of forming a sectional explosive charge was used, including the placement of charges in wells dispersed into sections by inert gaps, where each gap between the sectional charges was formed in the form of a capsule, with cylinders with completed diagonal slots made of heat-resistant material placed in it, and an initiator was installed in each sectional charge to carry out sequential detonation (Raskildinov, 1996).

To determine the length of the active bottom and wellhead parts of the charge, it is necessary to know the observation point that will characterize the rational distance from the end of the borehole charge. In order, to take into account the given distances at given points, it is necessary to bring the elongated charge to an equivalent concentrated one. For this purpose, the mass of concentrated charges equivalent to elongated ones was determined (Egemberdiev et al., 2019: 10).

After the explosion, the recaptured rock mass near the cutting gap is unloaded. Then the whole process is repeated for the remaining ring holes.

The results of experimental studies

The results of ore extraction indicators in the drift with the SBS method indicated that this method gives the highest percentage of ore extraction, on average 105.4 %. The delay time in the upper part of the drill ring SBS was 12 ms, and in the lower part – 70 ms. The reason for choosing a delay time of 12 ms. in the upper part of the drill ring, the SBS was to try to achieve an effective superposition of stresses from two adjacent wells.

To assess the impact of the changes received on the process of conducting DBO, it is necessary to check the consequences of applying solutions in practice. Modern methods of measuring the fragmentation of the exploded rock mass with the PortaMetrics device, serial number PM2136, using optical visualization and proprietary artificial intelligence algorithms to determine the granulometric composition were applied. This method was used in the face and on the surface in the bodies of underground dump trucks.

When analyzing with the "PortaMetrics" device, it was required that three images were taken at different angles at each sampling point, after which a general diagram of the granulometric composition of the two methods of explosions in drill rings was created.

An example of "PortaMetrics" images taken from three different sampling points and the corresponding diagrams of the granulometric composition are shown in Fig. 2 (a), (b).

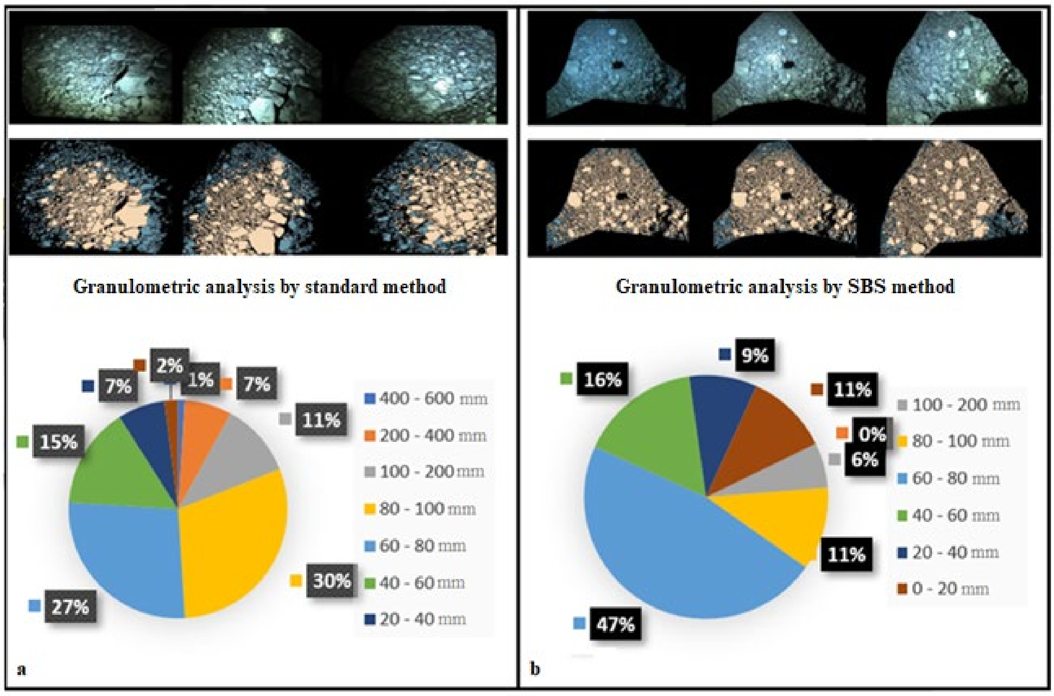

Figure 2. Analysis of the granulometric composition of the exploded mass.
a - is the standard method, b - is the SBS method.

It follows from the diagrams that the percentage of granulometric composition shown in Fig. (2 b), in the range from 60 to 80 mm with the method of SBS explosion is significantly higher than the same values with the standard method of explosion exceeding. The diagram also shows that very large fractions from 400 to 600 mm are absent.

The brightness of the lighting is one of the main factors affecting the correct reading of the PortaMetrics device. The question is whether larger fractions are illuminated and captured in the lens of the device, or they are in an inaccessible area, which can lead to significant differences.

In order to minimize the percentage of error of the granulometric composition in underground conditions, we additionally carried out measurements on the surface in the bodies of underground dump trucks, the results of which are shown in Fig. (3). The photographs show that with the standard method of conducting explosions, large fractions are present (fig. 1), and with the SBS method they are much smaller (fig. 2).

Figure 3. Photos of mountain masses in the bodies of loaded dump trucks on the surface.
1 – with the standard method, 2 – with the SPS method.

One of the negative problems with the implementation of the SPS is that in most mining operations, operators of underground loaders cannot constantly load dump trucks strictly up to the nominal load capacity, dump trucks are either underloaded or overloaded. Conditions that prevent stable loading include variables such as density, fractional composition and grade of the transported rock mass, such as empty rock during preparatory, rifling operations and rich ore.

Thanks to data collection, monitoring and analysis, operations management can achieve the necessary transparency of the transportation process, be able to establish and ensure compliance with its strategy of rules for loading mining equipment (10-10-20) Fig. 4 (CAT®, 2020).

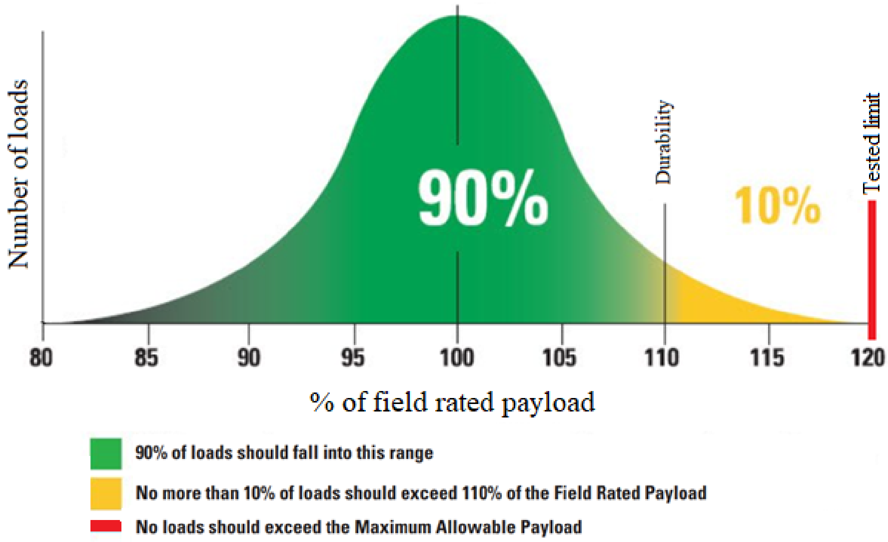

Figure 4. The 10/10/20 Caterpillar loading policy.

The weighing device can help in determining the actual load based on the fractional composition of the rock mass, as well as further improve the following indicators of mining equipment, such as (Viewpoint, 2013):

- Determine the payload and increase performance;
- Increase the return on investment in the motor park;
- Improve operational efficiency;
- Reduce fuel consumption and reduce exhaust gas emissions;
- Reduce overall operating costs, including crushing equipment;
- Reduce maintenance costs;
- Extend the service life of loading and transportation, crushing and sorting equipment, components and tires.

To solve these problems, "Transcale AF400" scales were installed in the underground mine, consisting of a stationary receiving device, a portable receiving computer device with remote weight fixation and two weighing platforms. Brief technical specifications are given in Table 1.

Table 1. Brief technical characteristics of the "Transcale AF400" scale system.

№	Position	Weight, kg	Size, mm
1	Platform No. 1	4700	3400x2300x440
2	Platform No. 2	4700	3400x2300x440
3	Calibration group	2000	2550x2080x1000
4	Stationary control system	15	500x400x300
5	Remote control system	0.5	240x100x40
6	The range of the percentage of error	0,1 - 0,4%	

The CAT AD30 dump truck (Table 2) was loaded in 5 cycles by the CAT R1300G loader with a bucket volume of 3.1 m^3. After that, the dump truck moved to the "Transcale AF400" weighing device. A total of 58 weighings were made, 29 weighings after the explosion by the usual method and 29 weighings after the SBS method, Fig. 5.

Figure 5. The process of weighing an underground dump truck CAT AD30 in underground conditions.

Table 2. Brief technical characteristics of the underground dump truck CAT AD30

Loaded dump truck weight, tonnes	Load capacity, tonnes	Empty weight, tonnes	Body capacity, m^3
60	30	30	14.4

Table 3 shows the actual data of the dump truck weighings, after four weighings of the empty dump truck and calculating the average value, the weight of the empty car was 29.8 tons. At each subsequent weighing, the weighing device system minus the weight of an empty car from the total weight of the dump truck with the output of the results of the actual weight of the cargo in the body.

Table 3. Actual weighing data of the CAT AD30 underground dump truck.

CAT AD30 garage number	Date	Empty dump truck weight	Loading of CAT AD30 dump truck on scales. With the standard method of explosions, t	Dump truck overloads 10/10/20	Loading of CAT AD30 dump truck on scales by SBS explosions, t.	Dump truck overloads 10/10/20	The difference in overload readings. The standard method of explosions and SBS method, t
01	26/01/2020	29.8	39	Yes	31	No	8
01	26/01/2020	29.8	41	Yes	33	No	8
01	26/01/2020	29.8	38	Yes	34	No	4
01	26/01/2020	29.8	40	Yes	33	No	7
01	26/01/2020	29.8	36	Yes	32	No	4
01	26/01/2020	29.8	36	Yes	35	No	1
01	26/01/2020	29.8	34	No	31	No	3
01	26/01/2020	29.8	35	No	29	No	6
01	26/01/2020	29.8	38	Yes	36	Yes	2
01	27/01/2020	29.8	37	Yes	33	No	4
01	27/01/2020	29.8	38	Yes	35	No	3

01	27/01/2020	29.8	41	Yes	32	No	9
01	27/01/2020	29.8	36	Yes	29	No	7
01	27/01/2020	29.8	39	Yes	35	No	4
01	27/01/2020	29.8	41	Yes	32	No	9
01	27/01/2020	29.8	34	No	31	No	3
01	27/01/2020	29.8	29	No	36	No	-7
01	27/01/2020	29.8	33	No	34	No	-1
01	28/01/2020	29.8	36	Yes	31	No	5
01	28/01/2020	29.8	37	Yes	33	No	4
01	28/01/2020	29.8	44	Yes	30	No	14
01	28/01/2020	29.8	39	Yes	32	No	7
01	28/01/2020	29.8	41	Yes	35	No	6
01	28/01/2020	29.8	37	Yes	31	No	6
01	28/01/2020	29.8	33	No	30	No	3
01	28/01/2020	29.8	35	No	35	No	0
01	28/01/2020	29.8	34	No	34	No	0
01	28/01/2020	29.8	39	Yes	31	No	8
01	28/01/2020	29.8	40	Yes	33	No	7

Discussion

As can be seen from the diagram in Fig. 6, with the standard explosion method, the loaded rock mass exceeded the nominal value in terms of load capacity in almost all cases (in the range between the red zones), which indicates that the fractional composition of the exploded mass was greater than permissible. On the contrary, after the SBS explosion method, all the data after weighing were within the permissible limits of the dump truck's load capacity (the range is from the green line to the red line).

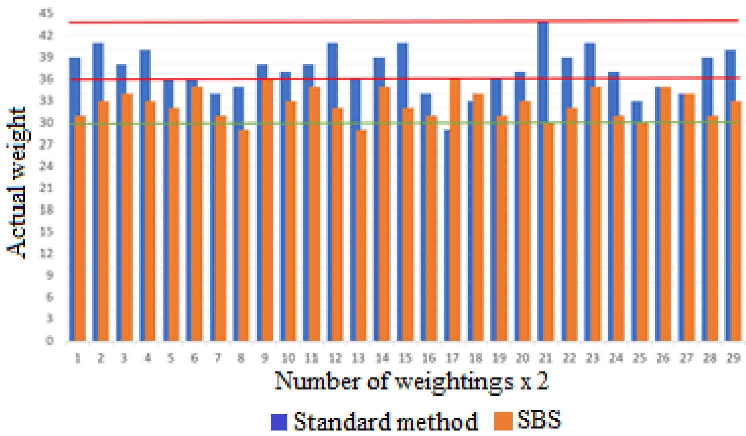

Figure 6. Diagram of underground dump truck loads.
(blue) for the standard method of explosions, (orange) for the SBS method.

A comparison of the results of the performed studies of the standard and improved (SBS) methods showed that an increase in the extraction of minerals is achieved by the fact that more ore is available from the upper part of each well with the SBS method than with the standard method, this helps to reduce dilution, since the empty rock above the drill ring during the SBS explosion will flow down later than with the the usual method. At the same time, the specific charge in the SBS wells is slightly higher than in conventional wells, since the distance between the drill rings in the SBS is about 3.2 m, and in conventional from 3.6 to 4.0 m.

To mine steeply falling ore deposits (dykes) of low power from 1.5 to 3 m, located in areas with very unstable host rocks, it is necessary to use a variant with sub-storey drifts and the formation of inter-chamber pillars (Egemberdiev et al., 2019:12).

Conclusions

By the measurements carried out, it was found that with the standard method of blasting, the amount of loaded rock mass exceeded the nominal value for the load capacity of the dump truck in almost all cases in the range located between the red zones, this confirms the conclusion that the fractional composition of the exploded mass was large-sized. On the contrary, with the SBS blasting method, all similar data after weighing were within the permissible limits of the dump truck's load capacity.

According to the results of the conducted research, the following conclusions can be drawn:

- extraction of ore from drill rings with an SBS system is higher than with the standard method in low-power ore bodies;

- measurements of fragmentation of the exploded rock mass by the «PortaMetrics» device showed that the percentage of granulometric composition in the range from 60 to 80 mm with the SBS explosion method is significantly higher than the same values with the standard explosion method and exceed them by 1.8 times;

- the SBS blasting method has a great advantage, in addition to safety and a greater degree of extraction, the SBS results in a finer fractional composition of the rock mass compared to the standard blasting method. This advantage lies in the fact that drill rings with the SBS method have a greater degree of extraction due to a larger number of partially free areas, as well as a greater concentration of energy in their upper parts. Such a high coefficient of swelling of the rock mass leads to a lower dilution, since the change in the volume of rocks depends on the nature of destruction, their genesis, humidity, initial granulometric composition, as well as the time they are in a loose state;

- in low-power ore bodies, the SBS method was successful in increasing the percentage of ore extraction and reducing lumpiness, this allows to significantly reduce operating costs not only for loading and delivery equipment, but also for crushing and sorting operations.

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