Blast advance optimization in underground stopes

Inês Costa Nascimento

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Abstract

The mining cycle operations rate is as important as the advance by *drift* blast. These variables are the most important in the yield evaluation of the operations in an underground mine. Good advances by blast minimize the excavation costs since the number of cycles to accomplish the same length is lower. With less blasts, the stope execution time is also shortened which allows the ore to be broken in a faster and cheaper way.

The present dissertation was done with data collected in the Neves – Corvo mine with the goal to increase the blast advances on *drift* stopes. For that propose, was started a process to collect information in order to find improvement opportunities on the operations that were being monitored during shifts. So, for about one month, the drilling, charging and scaling operations performed on *drift* stopes were studied in detail.

On the initial stage were identified the following improvement opportunities: increased focus on mechanical scaling and a few modifications in the drilling pattern, such as the change in rows number and the burn cut design. These variables were put to test and it was reached the conclusion that a thorough mechanical scaling and the additional rows in the drilling pattern increased the blast advance, therefore these findings were put into practice all over the mine.

Key-words: Mining cycle, blast advance, *drift*, drilling, charging, scaling, drilling pattern, burn-cut.

1. Introduction

In the present day, the search for ore stocks keeps raising due to technological evolution and the continuous increase of daily society needs. From 1991 to 2015, copper extraction has doubled worldwide – 9,3 to 18,7 million tons. With this scenario and since the mineral resources aren't renewable, mine explorations with higher grades are becoming rarer. The miner companies are shifting their focus to the remaining mineral reserves where most of stopes have low grades. For this reason, it's crucial that operations have great efficiency so the lower incomes don't affect the company's financial stability [1]. Mining method selection is one of the most critical and problematic points to consider too, since its goal is to maximize profit and ore recovery without forgetting workers safety conditions [2].

An underground mining method consists in a sequence of unit operations related to production that are repeatedly executed on the rock massif. The difference between all the methods are the operations techniques which change in each one. Only mucking, extraction and ore haulage remain constant for all scenarios. The mining method is selected according to the rock reaction to exploration, therefore it can be classified by the type of support that is necessary to ensure the overall stability – supported by pillars, with artificial support and without support [3].

On the artificially supported methods is required the use of mechanical supports, such as rock bolts, cable bolting, mesh or others, to control the roof and walls stability, not only from the stope in production but from the surrounding rock too [3]. In the Neves-Corvo mine, the Cut and Fill method is in use, which is an artificially supported mining method where mechanical supports are in practice. Once the stopes are fully explored, they are backfilled so the exploration is continued aside and above. In this method, the ore is obtained through the opening of horizontal galleries with the use of explosives, the so-called drifts. The method is appropriate to exploring high grade ore since it provides good recoveries. In the mine, there are several cut and fill ramifications that are selected accordingly to ore thickness – drift and fill, bench and fill, mini bench and fill and also optimized bench and fill.

Drifts are galleries with a 5 by 5 section that gain shape through a cycle of blasts until the ore is all explored. In Neves-Corvo, the drift blast efficiency is one of the most important keys to ensure the continuous ore extraction because it affects not only drift and fill stopes but also the other ones, since drifts are required to make bench's top and bottom accesses (drilling and mucking accesses, respectively).

The main unit operations of the drift cycle are drilling and charging because they can cause a higher cost impact and affect the performance of the following operations [4]. The unit operations are the essential ones to ore production, although the auxiliary operations shouldn't be discarded since they support the first ones and allow the continuous, efficient and safe works. A cycle is only considered finished once all its operations have been accomplished [5]. In the drift cycle, the unit operations are:

- Drilling (A);
- Charging (B);
- Blast (C);
- Mucking (E);
- Scaling (G);
- Mechanical Support installation (H).

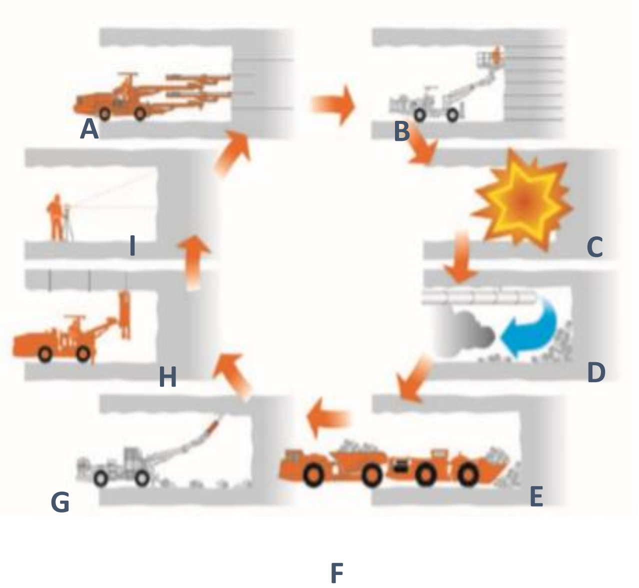

Figure 1 – Unit and auxiliar operations in the drift cycle (Heiniö, 1999)

Due to economic, social and environmental conditions that underground mines are currently operating, the auxiliar operations have been earning more importance in the blast cycle to ensure good work environments. The most common are the gas ventilation after blasts (D), hauling (F), work faces drainage, equipment's maintenance, surveying (I) and also energy, air and water supply [6].

The drilling pattern is a previously calculated grid that distributes the explosive over the rock depending on the results desired to obtained during the blast [7]. For an underground excavation, the drilling pattern must be dimensioned according to the length and diameter of the hole and the quantity and distribution of holes. The charges applied on the diagram series (burn cut, stoping, lifters and contour holes) will dictate specific charge and specific drilling [8]. The size and geometry of the gallery should also be taken into account as well as the geological and geomechanical conditions of the rock massif.

The main difference between a bench and a drift blast is that the latter has to be achieved with only one free face, that is, the gallery section itself, while in the benches are recognized at least two. The free face is extremely important because any blast needs an empty space so that the broken material have somewhere to expand. In drifts, the rock is more confined, so a second free face must be created for the blast to be successful. In this way, the burn cut concept (which can be done with parallel or converging holes) whose purpose is to simulate a second free face.

The drilling pattern is also used to dimension the amount and distribution of explosives to control the potential damage caused on the surrounding rock. The blast induced damage is mostly located near the excavation area and in the stope roof, walls and pillars [9].

2. Case Study

This article describes the attempt to increase the blast cycle yield on the Neves-Corvo mine. A blast cycle starts with drilling an ore face with certain section, followed by charging the holes and a posterior detonation; once the air is considered clear from gases created during detonation, the broken rock is mucked, then the unstable areas are scaled and is finally applied support according to the ground conditions. For this study, all of the cycle operations were monitored in order to find possible improvement opportunities.

At Neves-Corvo, a blast cycle includes five main operations. After blast, the ore is mucked to intermediate or final stocks (is in the last scenario that broken rock is ready to be loaded to dumpers and hauled to the crushing station). Mechanical scaling of the blasted area is next, which is an operation with a non-mandatory character; is consists in knocking down blocks with risk of falling that could mean jeopardize the workers and equipment safety. The support consists of the placement of swellex or rock bolts with injectables resins on the drift roof and walls. The number of units needed to apply differs with the ground conditions and is dictated by the Rock Mechanics department. It can be necessary the application of extra support, namely cables and shotcrete too.

The drilling operation is carried out with a two-arm rig. The holes are drilled parallel to the intended advance according to in a previously defined drilling pattern. In the burn cut area, there should be a lower spacing compared to the rest of the grid and larger holes are drilled in the middle, in order to simulate the “free space” that provides a good blast. Then all the holes must be charged with explosives - in this case bulk emulsion (with the exception of the larger ones that must be clean).

The blast advance is one of the most important indicators that evaluate the yield of a cycle. At the beginning of this study, April 2016, the average blast advance was 3,3 meters, a value that was 50 cm below the target. For this reason, it was necessary to understand how each operation impacted the cycle and what changes could possibly be made to improve the blast advance.

For this study, were selected a few work faces that represented the diverse geological and geomechanical ore types found all over the mine. These work faces were monitored continuously, with teams available to collect information every shift. This monitoring has focus on the scaling, drilling and charging operations while it was being recorded the blast advance on the chosen faces. Each blast advance was calculated from the distance between fixed offsets and the face continuous advance.

From the initial monitoring, the responsible team decided to split the study into 3 following phases where in each one would be tested a change in the cycle, as can be seen bellow:

Phase 1	• Mandatory scaling of all blast with equal focus on the work face, roof and walls; • Use of clay stemming on all charged holes.

Phase 2	Row addition to the drilling pattern to increase specific charge: • 9x8 grid to apply on hard and competent rock; • 8x8 grid to apply on soft rock.

Phase 3	Burn cuts with different geometries: • 2 large holes with 127 mm diameter; • 3 large holes with 102 mm diameter; • 3 large holes with 127 mm diameter.

3. Phase 1 Results

In the Neves-Corvo mine, ore is presented in massif or fissural form, that is, veins disposed in embedding rocks, the most common being shale, volcanic rocks and also quartzites. As a rule, the stopes that are presented in massive way are characterized by greater geomechanical competence (less fracture and greater hardness) so they are associated to better yield advances, as there are less weakness plans where the explosive force can dissipate. On the other hand, the work faces where ore is disposed in veins (fissural), its competence is dictated by the embedding rock. In general, shales have low competence due to the typical friability of this rock. However, it is common to find mixes of different embedding rocks like shale contacts with volcanic rocks as well as shale with quartzites. This appearance of more than one embedding rock in one stope has a tendency to have a slightly higher competence than when only shales are found, however never near the massif’s properties.

The fragmentation degree observed on the work face is a variable that can have a great impact in blast performance, given that on a very fractured face it is difficult to drill a clean hole and without deviations which allows their correct charging. A complete scaling operation can reduce face fragmentation and, consequently, improve the quality of subsequent drilling.

On Table 1, the fragmentation degree and scaling quality (good, medium or bad) are crossed. It is verified that good scaling operation when there are low or non-existent fractures leads to high advances (over 90%). However, as the scaling quality decreases, even with reduced fractures, the yield advance lowers 15%. On the other hand, with a complete face scaling, there is always obtained good advances.

Table 1 - Relation between rock fragmentation and scaling operation quality.

SCALING / **FRACTURATION**	GOOD	MEDIUM	BAD
Non existent	91,94%	76,93%	-
Low	92,19%	78,77%	76,17%
High	-	-	49,70%

Is was also recorded the average advances achieved with scaling which were grouped according to the type of rock (Table 2). It was found that, in average, the scaling operation not only removed the broken rock to improve drilling conditions, but also could provide little advances in its own – 39 cm. The company decided to make scaling mandatory each of the blast cycle.

Table 2 - Average advances seen when the work faces are properly scaled.

ROCK TYPE	AVERAGE BLAST FROM SCALING (M)	CASES
MASSIVE SULPHURET	0,10	4
SHALE	0,49	6
VOLCANIC	0,08	1
SHALE AND VOLCANIC	0,82	2
TOTAL	**0,39**	**13**

The same procedure was used in the stemming test (Figure 2). There was a large yield blast increase in shale rock and a slight improvement in the massifs. However, the significant difference for the first case meant that the stemming use became mandatory in the mining cycle.

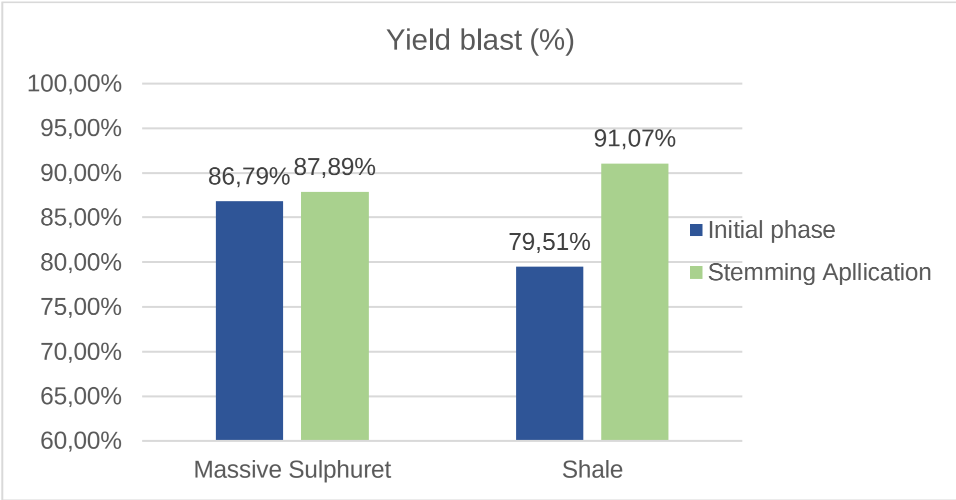

Figure 2 - Comparation of the results found in the initial phase with the ones found with the stemming application in all charged holes, according to the type of rock.

4. Phase 2 Results

In phase 2 tests, it was analyzed the effect of adding a row to the drilling pattern for hard and for soft rock, being considered, respectively, a 9x8 and 8x8 grid (Figure 3). This new design aimed to increase the specific charge to blast a drift with a 5 x 5 meters section. In this way, increasing the amount explosive to the same volume of rock, was expected better blast advances. However, the increase in explosive consumption could create instability in the surronding rock as the vibrations and impact created would be higher. Is was always important to evaluate the broken ore size to verify if the new specific charge was higher than the needed to dismantle that rock volume – too small rock sizes would indicate that.

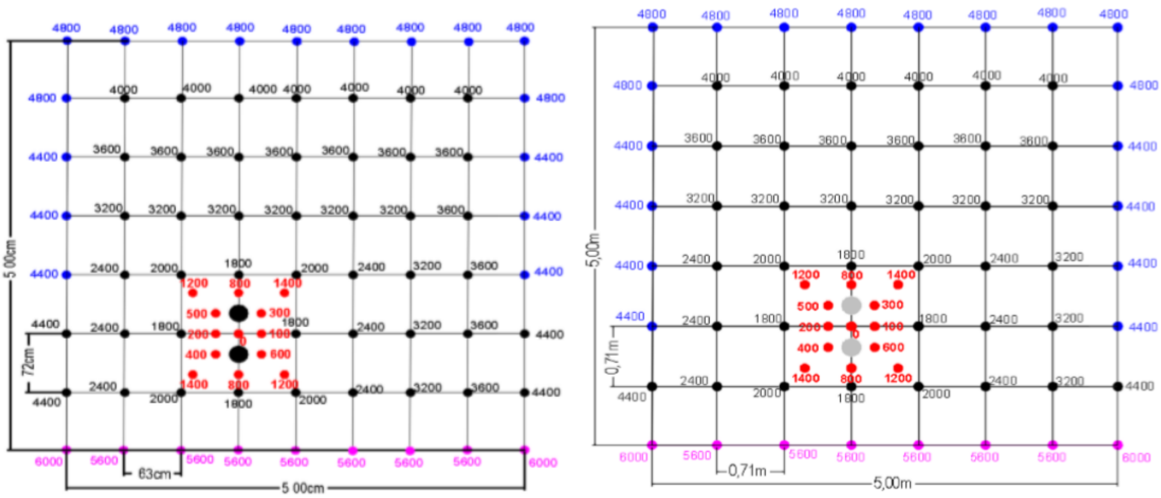

Figure 3 - Drilling patterns used in the increase of specific charge test.

For all types of rock considered, there was a significant increase in advances. With the obtained yield blasts, it was possible to state that the increase in specific charge per blast translates into a “certain advance”. This term is intended to say that good results are easily obtained, even if the performance of any task is not done with the possible accuracy. In this way, it could not be in an optimal state in the relation of cost cycle and blast advance.

Phase 2 of this dissertation allowed to conclude that the increase of one row in the drilling pattern for soft and hard rock mostly translates into a significant increase in blast performance (Figure 4). In addition, it was still possible to prove that the increased explosive use did not bring instability problems to the surrounding rock. The broken ore continued to present a granulometry within the values accepted in the mine. For this reason, the increase of a row to the drilling pattern was implemented on all mine stopes.

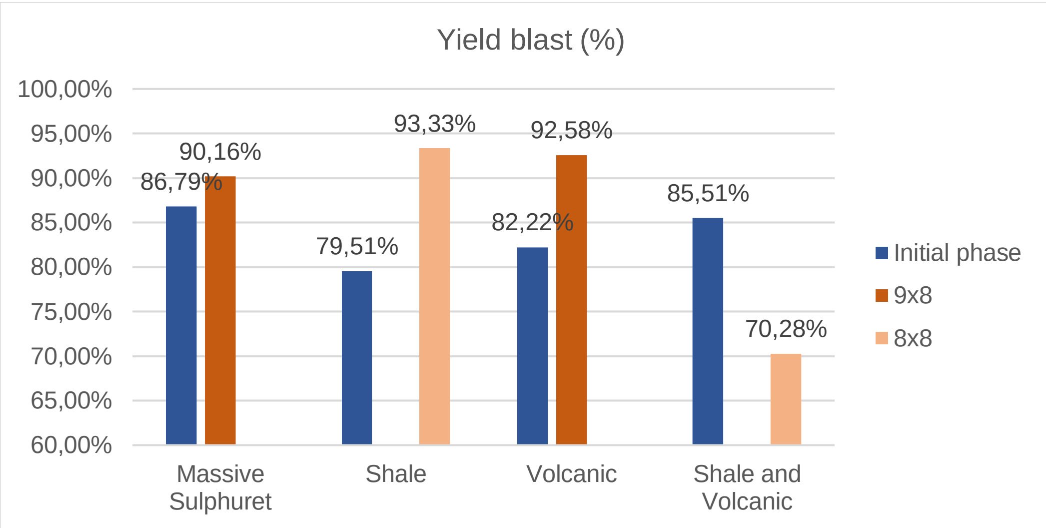

Figure 4 - Comparation of the results found in the initial phase with the ones found with increase of specific charge test, according to the type of rock.

5. Phase 3 Results

During the third and final phase of this study, three different types of burn cuts were tested that were similar to the one in use at the time. The initial one had two large holes with 102 mm diameter. The ones to test had: two 127 mm large holes, three 102 mm large holes and three 127 mm diameter (Figure 5). However, the test results turned out to be inconclusive. For the case of massif work faces, the blast yield was always greater than 88% in any situation. The values presented were so close that it was difficult to draw any direct conclusion. On the other hand, in the shale stopes, the best advances were registered in the previous phase 2, although there were still found good advances when testing for the two 127 mm large holes burn cut. The same was verified for the faces with volcanic embedding rocks where the best results were found in the also in phase 2. Finally, the stopes in shales and volcanic rocks also showed low yields, with the exception of the two 127 mm hole test.

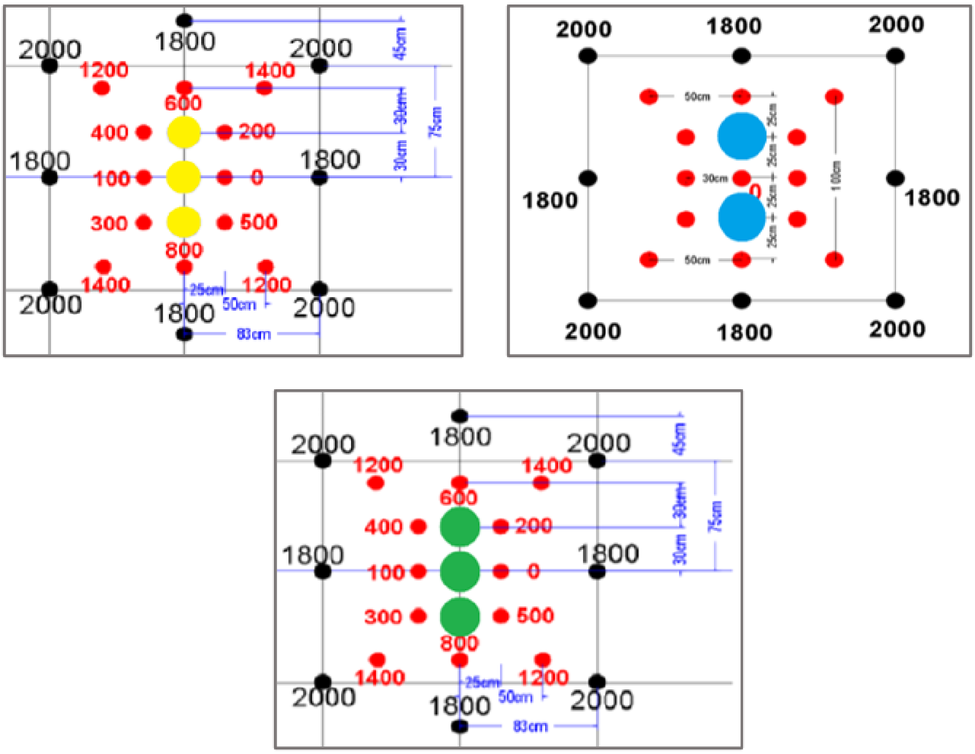

Figure 5 - Different burn cuts to test in phase 3.

In the end, the only burn cut diagram tested that revealed positive results was the one where the two large holes were increased to 127 mm (Figure 6). However, it took much more time to widen these holes than to 102 mm (about twice as much). It was also verified a greater wear of the rig steel components given the need to slightly higher drilling pressures. With these results, it's not possible to state that the data collected is accurate enough to put into practice any of the burn cuts tested.

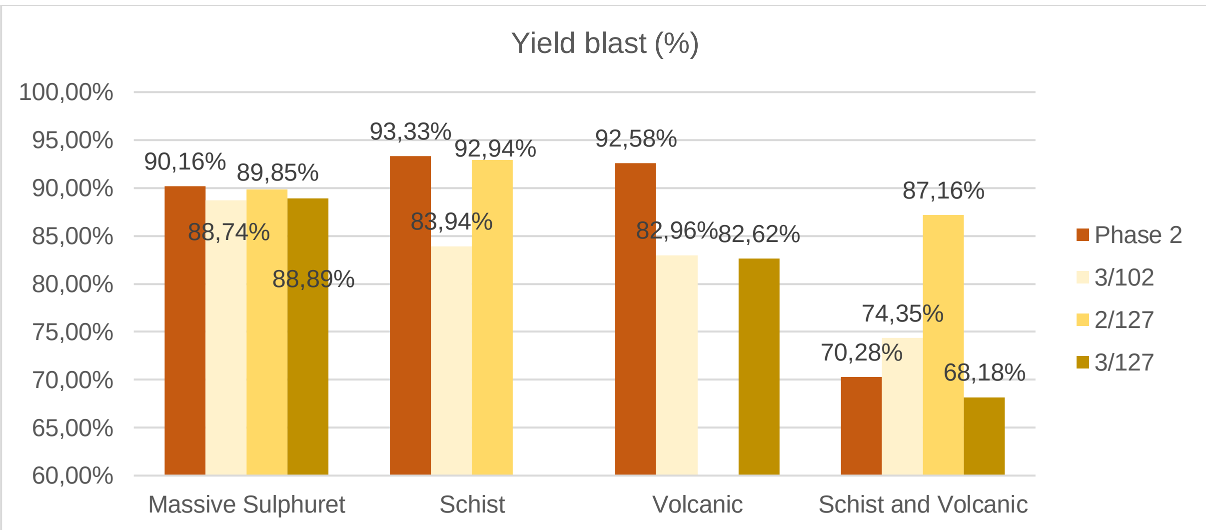

Figure 6 - Comparation of the results found in phase 2 with the ones found with the test of the different burn cuts, according to the type of rock.

6. Conclusions and Future Works

This dissertation aimed to study the operations that constitute the mining cycle and to identify improvement opportunities in order to increase the advance per blast. This study was carried out in the production work faces of the Neves-Corvo mine, where, at the start, the average advance was 3,3 meters, that is, about 50 centimetres less than the company target.

The study was divided in an initial stage, were data was collected in order to know the cycle operations and the difficulties associated to them. By being familiar with the operations, it was easier to identity possible improvement opportunities.

With this information, 3 following test phases there was developed with different goals. Phase 1 aimed to check the scaling and stemming use impact on advances. Is was concluded that both, when properly executed, lead to greater yields.

On phase 2 was tested the addition of a row on the drilling pattern with the goal to increase the blast specific charge. Very good results were found, so the new 9x8 and 8x8 grids were put into practice.

Finally, the phase 3 focused on the study of new burn cuts however the results found weren't conclusive enough so that a permanent change to the mine stopes would be justified.

As a final consideration, I would like to stress that the optimization of mining operations must be a continuous process, where there should be space for testing new emerge technologies and constant tests, like this one, to try to find improvements in operations. Given the rapid dynamic of ending and opening new stopes, it must exist the attempt to always improve drilling patterns that are constantly adapted to the different types of rock that are being explored.

7. References

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