Productivity Improvements in Tunnel Development, Using Drill Rigs and Shocktube Initiation Systems, at Bafokeng Rasimone Platinum Mine

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SYNOPSIS

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At the beginning of June 2002, BRPM North shaft had only 5 months ore reserves available. This was due mainly to sinking of the decline shaft being behind schedule and high or higher than planned geological losses being encountered on the upper levels of the shaft. In order to meet the required build-up of ore reserves, it became imperative to increase the rate and quality of waste tunnel development on strike on all the active levels of the mine. To do this by the introduction of trackless mechanised boom rigs was not feasible due to the high capital outlay this would entail, together with the need to recruit and train skilled operators and maintenance staff.

By July 2004 BRPM North shaft had increased ore reserves to 15 months due mainly to the successful implementation of a railbound tunneling drill rig, designed to provide accurate and safe drilling while reducing the dependence on operator skills and costing only 10% of trackless mechanised boom rigs.

Accurate and safe drilling has in addition provided a platform to optimize the quality of blasting and derive the benefits of explosives efficiency by allowing longer rounds and advance per round, together with improved fragmentation and reduction in overbreak.

INTRODUCTION

Bafokeng Rasimone Platinum Mine is situated approximately 10km south of Sun City and to the west and up dip of Impala Platinum’s property. Bafokeng Rasimone Platinum Mine consists of the North and South decline shaft systems, also D-mine which extend to 5 level and constitute phase I of the mining programme. Planned production is 215kt per month which includes disruption shifts once a steady state of production has been reached. Establishment of the present surface infrastructure and decline shaft systems commenced in 1997, with the buildup to full planned production still in progress.
MAINTENANCE AND EXTENSION OF ORE RESERVES

North Shaft production is planned to build up to 108kt of reef per month by 2007.

Due mainly to geological influences that impacted adversely on the availability and mineability of ore reserves at the North Mine as well as the sinking of the main decline being behind schedule, the required rate of creating ore reserves was seriously affected. It was thus imperative to create additional ore reserves at this shaft as soon as possible, in order to maintain the planned production requirements.

Development Layout

The present mining system is conventional breast mining, based on footwall haulages placed ±32m below the reef horizon, crosscuts to reef spaced at 200m on strike and level to level raises. Levels are spaced at ±45m vertical intervals. The original up-dip mining layout provided for 30m boxholes developed out of the haulage for each panel. However due to the congestion caused by tramming operations, it was decided to change to the present layout.

Required improvement to sustain and increase ore reserves

At the beginning of June 2002 the available ore reserve represented only ±5 months of production. To facilitate the buildup of production to the planned level of 108kt per month it became strategically necessary to improve this ratio to at least 15 months of production.

Total waste development per month over 4 levels at North shaft was averaging 110m per month. In order to achieve the above requirements, it was necessary to increase this rate to more than 150m per month.

Other than for sinking and station development, the mining and ventilation infrastructure does not allow for the introduction of multi shift or multi blast development operations, so the option selected was to increase the standard round drilled, from 2.5 to 3.2 meters.

MOTIVATION TO PURSUE PARTIAL MECHANIZATION

Increases in development rates were required simultaneously over multiple levels. This in turn, would necessitate the purchase or lease of a number of drill rigs drilling only one or two rounds per day on specific levels.

Initial trials had shown that it was feasible to adapt the stope drill rig thrusting system to a rig that could be used for the drilling of large end development rounds.

Factors mitigating against the deployment of diesel or electric powered, trackless drill rigs were:

- High capital investment or leasing cost of trackless drill rigs in relation to the number of development ends available per drill rig. The cost for fully mechanized rigs ranges from approximately R1 million to R3 million. (In comparison to ±R300 000 for the Novatek Rig);
- High operating costs of trackless equipment;
- Scarcity of skilled operators and qualified maintenance personnel;
- Integration with trackbound rockhandling systems. Levels are equipped with a conventional tramming system using trackbound locomotives and hoppers to service stoping operations;
- Standard Rocker Shovels are employed for cleaning of broken rock from development ends, which further inhibits the use of mechanized rubber tyred drill rigs.
Based on prototype designs and estimates, it was considered possible to produce a drill rig capable of providing accurate drilling of longer rounds at approximately one tenth of the cost of a typical, fully mechanized diesel or electric powered drill rig.

**CHALLENGES PRESENTED**

**Operators**

When BRPM took over the level development from the Contractors who sank and equipped the decline shafts, there was a shortage of experienced and skilled rockdrill operators for conventional handheld rockdrilling systems.

As part of the joint venture agreement with the Royal Bafokeng, BRPM had undertaken to recruit novice workers from the local residents who would be trained in the necessary areas of operation.

From the outset, inexperienced operators had difficulty in drilling rounds with the accuracy needed to achieve advances of more than 2 meters per day in 3m x 3m development ends. For the same reasons the drilling of roofbolts was also a problem in these ends and as a result, safety became a major concern.

Physical ability and skill of these operators in handling heavy rockdrills and long drill steel, inhibited their ability to drill even longer (3.2m) rounds and achieve a blast on a daily basis.

**Equipment**

The challenge was to design and develop a basic drill rig that could integrate with rocker shovel cleaning and trackbound tramming, whilst enabling rockdrill operators to drill accurate 3.2m rounds in major development ends on a daily basis. Big rocks produced from development blasting cause delays in the decline shaft conveyor system and create possibly hazardous conditions for persons working and traveling in the shaft.

To ensure the safety of operators while drilling the face, they need to be clear of the high risk area between the face and the front of the drill rig and be working in from an effectively supported position.

**Blasting System**

The benefits of accurate drilling could only be realized by the introduction of an accurate initiation system capable of providing the maximum advance per blast, while producing uniform fragmentation, providing better control of overbreak and minimizing blast damage to the hanging and sidewalls.

**Implementation of New Technology**

As with any new (or different) technologies or systems, the implementation process must be formally structured and planned to ensure acceptance and ‘ownership’ by the users. This process is well documented in several publications and the challenge in this case was to define and implement these recognized processes for this project.

To this end, a ‘Champion’ was appointed whose sole responsibility was to facilitate the implementation of the Drill Rig System. The scope of his appointment was to liaise with the Suppliers; Supervisors and Managers of the production sections where the LED rigs were operating and the Mining Optimization section. In addition he was responsible for selecting and training
operators, maintenance of the LED rigs and proposed design alterations to improve the efficiency of the equipment.

Management buy-in is crucial in the success of any innovation and in this case the Business Area Manager gave his full support and commitment to this project.

**EVOLUTION OF THE LARGE END DEVELOPMENT RIG**

**Stoping Drill Rig**

The Novatek stoping drill rig was being very successfully used in stoping operations at North shaft. This drill rig is essentially a thrust cylinder, onto which a rockdrill is attached by means of a sliding carriage. The thrust cylinder is in turn mounted onto a supporting pipe that runs parallel to the stope face for the full length to be drilled. Either conventional compressed air power with pneumatic rockdrills, or alternatively high pressure water with water powered hydraulic rockdrills, can be used in the same configuration. This is a very basic description of the system that for clarity, is illustrated in Figures 1 and 2.

![Figure 1](image_url)

**Figure 1**

Stoppe Drill Rig
Creation of the Large End Development Drill Rig (LED)

Recognizing the advantages gained from the stope drill rigs, it was decided to extend the concept to drilling of tunnel development rounds and towards the end of 2000 four prototype 2.6m Novatek three boom drill rigs were manufactured and mounted on a platform attached to steel props that are used for support while drilling development ends. This application continued for approximately a year, as a trial to evaluate the system.

Even with this prototype system, the advantages of accurate drilling were realized in the terms of the following results:

- Better dimensional control due to reduction of overbreak;
- Improved breaking ratio, comparing length of hole and advance per blast;
- An excellent safety record - the operators are well back from the face;
- Significantly improved penetration rate - a 2.4m hole was drilled in 8 minutes (0.30m/min);
- More uniform fragmentation.

Building on the results obtained from the prototype rigs, the decision was taken to design a production model of the drill rig, that would be mounted on a railbound car with a length of hole capability of 3.2 meters.

At the beginning of 2002, BRPM and Novatek joined forces to design and manufacture several production LED drill rigs. Initially the length of holes was maintained at 2.6m but towards the middle of 2003 this was extended to 3.2m with great success.

Six Novatek rail bound rigs were in place at the end of 2003 with a spare on surface for rotation purposes in case of repair and maintenance.
THE SOLUTION WAS PROVIDED BY THE PRODUCTION OF THE NOVATEK LARGE DEVELOPMENT END DRILL RIG

The Novatek Large End Development Drill Rig

The system is mounted on a railcar and features a simple winch-powered mechanism to deploy the supports and feeds with a minimum of physical labour. A pneumatic winch is used to raise and lower the drill feeds to the correct drilling positions. A ‘normally on’ brake automatically holds the crossbeam and drills in position. Once deployed, the system is operated remotely from the rear of the drill car. Operators are only required to reposition the drills for each vertical row of holes. The same unit is also able to drill and install roofbolts and to drill cubbies and breakaways. Normal operation requires typically 3 persons.

By articulating the ‘crossbeam and tower’ unit the effective height of the drill rig can be altered from 2.8 meters when drilling, to 1.4 meters when traveling. This allows the rig to safely pass under for example ventilation and services pipe columns, through ventilation doors and to pass under rockpass chutes.

The following series of figures illustrates the drill rig and technical features.

Figure 3
Schematic layout of the LED Rig
REVIEW OF BLAST INITIATION SYSTEMS

Having provided the means for accurate drilling, full advantage of the longer holes and improved accuracy could only be realized by the introduction of a more efficient blast initiation system than the capped fuse and igniter cord still being used at the outset of the project.

The following is a brief overview of the concepts and outcomes of accurate initiation systems, together with a review of the results obtained by the implementation of the shocktube based ‘TunnelMaster’ system supplied by African Explosives Limited (AEL)
Characteristics of Initiation Systems

An explosives initiating system performs the functions of transmission and control of the firing signal to each explosive charge.

Results produced by any multiple-hole blast are critically dependent on interactions between the blastholes. The sequence in which the blast holes are initiated and the time interval between successive detonations, plays a major role in overall blast efficiency in terms of the following components of the blast process:

- Sequential firing;
- Movement of rock;
- Fragmentation of rock;
- Vibration.

Performance can only be optimum when blast hole charges are initiated in a controlled sequence, at suitably discrete, but closely spaced time intervals. Firing the same number of blastholes individually or at random, cannot duplicate the result of a well-designed multi-hole blast with accurate and precise timing intervals. The effect of more accurately controlled blasting is illustrated in Figure 6 below. As the precision of blasting increases with the introduction of more efficient initiation systems, the components of the blasting process, namely sequential firing; controlled movement of broken rock; vibration control; and controlled fragmentation progressively contribute to the reduction of damage caused by out of sequence or random firing, providing optimum advance and fragmentation.

![Figure 6: Factors affecting Blasting Efficiency](image-url)
Components of Initiation Systems:

- **Starters**: Those components that provide the initial signal to start the blasting process

- **Out of hole Systems**: Products that provide transmission of the starter signal and delay timing (if any) across the surface of the blast outside the blasthole. (e.g. fuse and igniter cord)

- **In-hole systems**: Products that provide the signal transmission, delay timing (if any) and the initial explosive energy in the blasthole. (e.g. shocktube with on board delay; electric detonator; electronic detonator system)

Commonly Available Systems

The most common grouping of initiation systems is by the method of signal transmission to the base technology. Systems in commercial use today are capped fuse/Igniter cord; electric detonators; detonating cord; shock tube based systems and electronic detonators.

- **Capped fuse and Igniter cord**: At best, we can control the sequence of the holes firing, the length of time between holes firing, means that each acts independently of the next.

- **Shocktube and Electric detonators**: Use pyrotechnic delay elements (zero to 7000msec) and the variation of the actual delay periods from nominal, is at the best about 1% standard deviation from the nominal in-hole delay. For 500 ms in-hole delays, this means that 95% of shots fire within 10 ms of the mean. i.e. a window of 20 ms. Using a fixed interval between shots of 25 ms ± 15 ms, a very ragged firing pattern could be expected which in practice could result in non-optimum fragmentation and advance.

- **Electronic Detonator Systems**: The negligible variation (±0,5ms) in the delay periods of Electronic detonators, enables the firing pattern to be consistently the same for each blast, resulting in uniform blast results arguably providing optimum advance and fragmentation.

Comparison of Costs

In order to compare the absolute costs of the above systems, it would be necessary to construct an economic model to factor in the full financial advantages of the characteristics of more efficient blasting systems.

However as an indication, the direct cost per meter advanced (for accessories only) would increase by ±31% for shock tube, and ±220% for electronic detonator systems.

IMPLEMENTATION OF A SHOCKTUBE BASED INITIATION SYSTEM

Survey of Blasting Efficiency in Drill Rig Development Ends

Before the conversion project started, AEL was requested by Bafokeng Rasimone Mine to conduct a base case study by means of blast surveys for a period of one month. The objective was to quantify and evaluate the system in use and to benchmark performance.

The round design for the waste haulages and crosscuts was based on a 2,5m deep, 58-hole burn cut, of which 57 holes were charged. At the beginning of the benchmarking study, three drill rigs were in use.

The blasting system consisted of Anfex, initiated by 2.4m Durafuses and timed with Duracord detonating fuse.
A total of 17 blast surveys were carried out on different levels where the drill rigs were being used and the following results were recorded:

- the total advance in these 4 development ends was 112,3m for the month of June 2002;
- average hole length measured was 2,5m with an average socket length of 520mm after the blast. (Average efficiency: 79% of hole length broken);
- problems with big rocks were reported by the night shift cleaning which caused delays in the cleaning of the ends.

The benchmarking exercise was completed by the end of June 2002

**Introduction and Implementation of the TunnelMaster Shocktube System**

*Initiation System*

Evaluation of the above results strongly indicated that a more efficient initiation system could significantly increase the breaking efficiency per round.

The ‘TunnelMaster’ shocktube system is a proprietary product supplied by AEL and features a series of 18 long period delays (ranging from zero to 7 000 milliseconds) contained in the detonator, that are configured to provide specific delays for the shot holes when connected together with Cordtex 10 detonating cord.

Because the delays are already in the blast hole, misfires due to cutoffs are eliminated.

The explosives system adopted consisted of Anfex, initiated with 3,5m ‘TunnelMaster’ shocktube detonators with a range of 18 delay intervals, connected by Cordtex 10 detonating fuse.

This project commenced in July 2002 using a 49 hole burn cut with 4 uncharged holes.

**Timing with Tunnelmasters and Cordtex**

The required firing sequence is achieved by using a combination of the millisecond delay detonators listed in the following table.

<table>
<thead>
<tr>
<th>Delay Timing Design, 2004</th>
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<tbody>
<tr>
<td>Delay No.</td>
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<td>Delay timing (ms)</td>
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<tr>
<td>Delay No.</td>
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<td>Delay timing (ms)</td>
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Once the shot holes have been charged, the detonators are connected to the detonating fuse that when initiated will in turn initiate the shocktube and detonators that will initiate in accordance with the delay value of the detonator.
**Results**

Initial results were disappointing because the reduction from a 2.5m deep, 59 hole burn cut to a 2.5m deep, 49 hole burn cut, created excessive burdens in relation to rock strengths.

The Mine Team in consultation with AEL, designed a new burn cut round, consisting of 54 holes of which 4 were uncharged. The initiation system remained unchanged.

Application of this new design commenced in mid August 2002 and was completed by October 2002 with the following results:

- The total advance per month, in the 4 development ends involved, increased from the 112.3m benchmark in June 2002, to 152.5m in October 2002 and 174.3m in November 2002. (Improvements of 35% and 55% respectively);

- Average hole length drilled was 3.0m with an average socket length of 440mm after the blast. (Average efficiency: 85% of hole length broken – an improvement of 7% from the benchmark 78%);

- No problems with big rocks were reported by the night shift cleaning crews;

- Fragmentation was more uniform and assisted the loading of broken rock and maintaining of the daily production cycle.

![Figure 7](image_url)

Figure 7
Sketch showing the burn-cut round, using ‘TunnelMaster’ shocktube delay detonators, connected with Cordtex 10 detonating cord
REVIEW OF PRODUCTIVITY BENEFITS AND RESULTS ACHIEVED

Operator Performance

The emphasis on physical strength required to handle and maneuver conventional handheld rockdrill and airleg combinations, is greatly reduced and allows the operators to focus on accurate drilling of the round.

Ergonomically, the operator is standing in a more secure position behind the controls, and is not subjected to the potentially harmful vibration experienced with handheld rockdrills.

Improvement in Development end advances

An average advance of at least 40m per month per drill rig can be expected. Constant advances of between 50m and 60m per month are being achieved. The best performance to date was 71m in a single end in January 2004.
The following table illustrates the results achieved over the period: It must be noted that these averages reflect the results of all the development ends included in the project.

**Loading the rock broken produced from the drilling of longer rounds**

Efficiency of any cyclic operation depends on the ability to balance all the components of the process and ensure that the planned cycle is maintained. In this case, the objective is to achieve a blast per development end per day. The result of blasting longer rounds and increasing the amount of broken rock by approximately 30%, initially made it difficult for the night shift cleaning crews to load and tram the broken rock in the shift time available. However once the Tunnelmaster system was introduced, the uniformity of fragmentation of the broken rock improved significantly and facilitated the cleaning rates so that the cyclic balance was restored. Significant effects resulted in a reduction of delays at the tips due to a reduction of ‘big rocks’. This in turn has contributed to a reduction of damage caused to the shaft conveyor belts resulting in improved belt life.

![North # Novatek Development Rigs](image)

**Table 1**

| Trend graph of advances per end per month |

**Fragmentation Analysis**

A fragmentation analysis of the typical results from fuse and igniter cord and TunnelMaster system was carried out to confirm the above findings.

**Results of the Analysis**

The uniformity index and characteristic size, Xc, (63.2% passing) for the Rosin Ramler curve are listed below.

It is normally desirable to have uniform fragmentation, thereby avoiding both excessive fines and oversize fragments in the broken ore. The Uniformity index (n) in the Rosin-Rammler equation gives a measure of this with values greater than 1 indicating a more uniform sizing, whilst lower values result in higher proportions of fines and oversize.

These results are illustrated in the following graph and indicate the improved uniformity of fragmentation obtained from the shocktube based TunnelMaster System. It can be seen that the proportion of fines has reduced and the percentage of rock that will pass through a 300mm X 300mm orepass grizzley is significantly increased.
Operating Expenses

**Spares**

One of the major considerations was to use standard parts and accessories that are readily available in the Mine stores. Seco S25 rockdrills are mounted on the thrust cylinders, the control console uses standard hoses and fittings as far as possible and additional spares costs for the drill rigs have only been of the order of R1 500 per rig per month.

![Graph of % Retained - Combined](image)

**Labour**

A typical drill rig crew consists of:

- A Miner
- A Loader Driver
- Three Rock Drill Operators
- A Drill Rig Operator
- Five Construction (PVT) workers

Based on the average advances per end per month, the labour productivity index has improved from 2.3m per person per month to 3.6m per person per month (an increase of 58%)
SAFETY

Risk Assessment

A detailed Risk Assessment of the use and operation of the drill rig was carried out to highlight any high risk-profile elements. The assessment indicated that risks are mainly due to injury from falling components such as props or traverse beams if not correctly installed or due to failure. It is important that props are correctly installed and checked periodically while in use. Reduction of the risks identified entailed the establishment of approved procedures coupled with specific operator training to conduct pre-use checks to reduce risk of failure if components become damaged in use.

Safety Achievements

No injuries have been recorded during the entire project to date.

One of the most significant improvements, has been that the operators are removed from the area between the drill rig and the face, where there is a high risk of injury from rock scaling from the hangingwall or sidewall.

In order to prevent falling loose rocks from the hangingwall from injuring the rig operators, four steel props are installed to support a safety net positioned over the drill rig. Roofbolt holes are drilled using the drill rig and are accurately positioned and drilled to ensure maximum effectiveness.

SUMMARY OF OBJECTIVES AND ACHIEVEMENTS

Objectives

Effectiveness and capability of fully mechanized drill rigs to provide the accuracy and effectiveness necessary for high speed development is undisputed. However, in order to realize the full payback on the capital investment, these machines must be deployed in an environment that allows them to be utilized to their full potential and are therefore not appropriate for this application.

The prime objective of this project was to increase the rate of waste development and so increase ore reserves to achieve and sustain planned production rates.

The secondary objective was to design and develop a cost effective, semi-mechanized drill rig that would facilitate the drilling of longer, accurate holes in waste development ends, by available semi-skilled workers.

Capital investment

The Novatek Large End Development Drill Rig provides a relatively unsophisticated means for normal rockdrill operators to safely and accurately drill rounds of at least 3,2m.

In general, the LED drill rig costs in the region of 10% of the average cost of a fully mechanized rubber tyred drill rig. (±R300 000 for the LED rig, compared to between R1million and R3million for a fully mechanized drill rig).
Running costs

Running costs have been kept at a minimum due to standardization, with most commonly used parts and fittings readily available, and the use of standard pneumatic rockdrills in general use on the mine. Average spares cost per rig per month are of the order of R 1500-00. Additional cost for the ‘Product Champion’ who has supervised and assisted the implementation of the drill rigs has been R15 000-00 per month.

Manpower

It has been possible to train and uplift local, relatively unskilled workers, to be able to successfully operate the LED drill rigs.

Blast Initiation System

The ability to drill longer more accurate rounds created a need for the introduction of a more effective initiation system that could extract full advantage from the drilling function. To this end, a commercially available shocktube based initiation system was configured, in collaboration with African Explosives Limited. (The ‘TunnelMaster’ System)

Opportunity cost of increasing ore reserves

A detailed financial evaluation of these implications is beyond the scope of this paper but consideration must be taken of the fact that at the outset of this project, it was imperative to increase the available ore reserves so that the planned buildup of production could be achieved and maintained. The implications of a ‘mill empty’ condition, as a result of not meeting the planned level of 215 thousand tons per month, created an ‘Opportunity Cost’ scenario, in that the ratio of losses far outweighed the situation of a ‘mill full’ conditions where emphasis is on cost reduction.

The LED drill rig has contributed to building up the required ore reserve ratio and is an example of what can be achieved in a collaboration between a mine and suppliers of equipment.

The ‘Way Forward’

As the mine progresses into ‘phase II’ to exploit the lower levels, the same pressures on ore reserve creation will continue. The concept of the present drill rig is being extended, by mounting the boom and drill thruster components onto the rear of a specially modified Light Delivery Vehicle (Bakkie). This should improve the mobility and flexibility of the railbound ‘flatcar’ unit, while retaining the inherent cost and efficiency advantages.

ACKNOWLEDGEMENTS

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