THE INTRODUCTION OF ELECTRONIC DETONATORS AT OPTIMUM COLLIERY

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SUMMARY

The last 20 years have witnessed dramatic progress in blasting technologies. The introduction of the high accuracy electronic detonator can be seen as the quantum leap in blasting science. The blasting community can become better equipped to improve upon the current approaches and methodologies of blast design. The accurately controlled sequence of blast hole detonation is one of the most critical parameters having a direct impact on overall blast performance.

Previous research done on quantifying the benefits of electronic detonators was confined to small test sites. These studies proved the accuracy and consistency of electronic detonator timing accuracy, improved fragmentation with subsequent productivity increases, and relevant cost savings.

The challenge was to implement electronic detonators at a large, full-scale production operation. In this scenario the real effect and or benefits of electronic detonators will emerge. Optimum Colliery is one of the largest opencast mines in the world.

The main objective behind the implementation of electronic detonators at Optimum Colliery was the possibility of explosive cost reduction. The implementation process was conducted with caution. Possible impact on production had to be minimised. Only small and single improvement changes were made at a time.

Data for analysis was captured as part of well established monitoring systems. The data capturing and analysis were thus in perfect correlation with historical procedures. The following benefits were achieved:

- Improved fragmentation.
- Improved dozer productivity.
- Improved dragline productivity.
- Reduced drilling requirements.
- Reduced drill and explosive costs.
- Reduced vibration and airblast impacts.

The use of the electronic initiating system is rendered safe through the application of technology, operating procedures and training. The implementation process at Optimum Colliery was extremely successful. There were however few learning points. Electronic detonators will provide benefits in any blasting application. This technology has been long awaited and hence will be embraced by the blasting community as a whole.

1. INTRODUCTION

Optimum Colliery is a major Colliery in the Ingwe Group producing coal from the Witbank Coalfield for export through the coal terminal at Richards Bay, for Eskom’s Hendrina Power Station and the domestic market. Eikeboom, a section of Optimum Colliery, produces metallurgical and steam coal for the domestic market and export market. The mining method at Optimum is multi-seam mining, using draglines in successive parallel strips 45 metres wide and up to 4000m long. This method involves removing the topsoil to a depth of approximately 1,25 metres, drilling and blasting the overlaying waste material and the removal of this overlaying burden by draglines. The exposed coal is then drilled, blasted and delivered to the HMS plant or to the Eskom wash plant.

The timing of blasthole firing has a direct impact on:

- Resultant fragmentation
- Percentage throw achieved
- Level of vibrations generated
- Level of noise generated

The timing/delay element of blasthole firing is enabled through a delay element in the detonator. In the pyrotechnic detonator this relates to burning through some material before the fuse head is reached. The delay element length would determine the delay period.

The pyrotechnic detonator design is such that the average scatter of delay firing is ±10%. This implies that for a blasthole that should fire at 25ms from initiation, might fire at 22.5ms or 27.5ms. This may not seem like a huge variance, but the resultant effect is. The scatter on a 500ms delay detonator will cause it to fire anytime from 450ms to 550ms i.e. a range of 100ms. If taken into account that interhole delays of 9ms are used on a blast, out of sequence hole firing is almost guaranteed.
The long awaited arrival of a high accuracy detonator provides new opportunities to the explosive end user. The blasting community can become better equipped and able to improve upon the current approaches and methodologies used in blast design.

The last 20 years have seen dramatic progress in blasting technologies, the quality and performance of products. The high accuracy detonator brought with it a new meaning to one of the fundamental aspects of blast design: accurate controlled sequence of blast hole detonation is one of the most critical parameters that has a direct impact on overall blast performance in many ways.

The measure of the potential effectiveness that the available explosives energy has to both break and displace the rockmass is directly proportional to the effective burden that energy must overcome. This relationship is a crucial element in basic blast design. Any variation in hole detonation timing that would result in a hole being fired prior to or after its nominal firing time while still remaining properly sequenced or firing totally out of sequence will result in burden to energy relationships that can have adverse impacts on the performance of a blast. These impacts have been evident throughout the years in terms of:

- Poor rock fragmentation.
- Large amounts of oversize.
- High ground vibration levels.
- High air blast levels.
- Flyrock incidents.
- Increased need for secondary blasting.
- Increased excavation and crushing costs.

Research has shown that the standard pyrotechnic delay elements that are currently being utilised throughout the world do not provide the accuracy necessary to consistently and measurably mitigate impacts. Within the last 10 years, several groups have produced and studied the use of high accuracy detonators and timing systems. These studies have concluded that accurate hole detonation would provide the explosives using industry with an increased potential to effectively minimise these adverse timing related impacts. All the research done on quantifying the performance of the electronic detonators was on small test sites, mainly quarry operations in America. These were sites specifically chosen and prepared to represent the ideal situation. These studies proved the electronic detonator in terms of:

- Detonator accuracy.
- Vibration prediction.
- Rock fragmentation.

The next challenge is the introduction of electronic detonators on a large full-scale production environment. This environment does not cater for the ideal test site and procedures. It is impacted upon by the reality of the day to day production operations and pressures.

The results from such a study would reveal the real benefits for a large open cast operation such as Optimum Colliery. The primary objective for Optimum Colliery to use electronic detonators was the possibility of reducing costs. Explosive costs form one of the major components of Optimum Colliery’s cost structure i.e. 35% of the total consumable cost during the 1999/2000 financial year. For various reasons South African operations are very cost sensitive. More efficient application of explosives implies less explosives to be used to create at least the same results as with pyrotechnics in terms of fragmentation.

1.1 IMPLEMENTATION STRATEGY

The strategy of implementing electronic detonators at Optimum Colliery was one of caution. The implementation process could not be allowed to impact negatively on production. The eight draglines expose ± 50 000 tons of coal a day. If there was to be under performance from a blasting point of view, it will impact negatively on dragline productivity. If the dragline does not expose coal, the coal can not be extracted with obvious effects on Optimum Colliery’s business.

The basic strategy was to start the use of electronic detonators on exactly the same parameters pertaining to pyrotechnical detonators at the time. Results were evaluated and on the basis of continuous improvement only small changes were made at a time. This process was repeated through a few stages until an optimal result was achieved. Data in terms of blast performance, dragline productivities and costs was captured throughout the process. This information forms the basis of the analysis and stands proof for claimed improvements.
The data captured and used forms part of the normal production monitoring system in place on the mine. No special systems had to be developed or put into place. All data needed for analysis was available on well established systems and data basis. Although the focus was on cost saving, results from previous research projects made it evident that improvement in terms of vibration and airblast could also be expected. The results were also captured within the established monitoring system. The relevant data was drawn for analysis.

1.2 ELECTRONIC vs PYROTECHNIC

The differences between the two systems can be summarised to fall into two main categories i.e. those relating to the timing accuracy and those relating to the reliability of a blast:

<table>
<thead>
<tr>
<th>TIMING</th>
<th>PYROTECHNIC INITIATION SYSTEM</th>
<th>ELECTRONIC INITIATION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Detonator accurate within a 10% range.</td>
<td>1. Detonator accurate to within 1 ms.</td>
</tr>
<tr>
<td></td>
<td>2. Lead (delay) times on shock tube.</td>
<td>2. No lead (delay) times on detonator connectors.</td>
</tr>
<tr>
<td></td>
<td>3. Lead (delay) times on detonating cord.</td>
<td>3. No lead (delay) times on harness wires.</td>
</tr>
<tr>
<td></td>
<td>4. Limited timing scenarios available.</td>
<td>4. Any timing scenario possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BLAST RELIABILITY</th>
<th>PYROTECHNIC INITIATION SYSTEM</th>
<th>ELECTRONIC INITIATION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Detonator functioning unknown.</td>
<td>1. Detonators functionality known.</td>
</tr>
<tr>
<td></td>
<td>2. Shock tube functioning unknown.</td>
<td>2. Detonator lead functionality known.</td>
</tr>
<tr>
<td></td>
<td>3. Detonating cord functioning unknown.</td>
<td>3. Harness wire functionality known.</td>
</tr>
<tr>
<td></td>
<td>4. 100% Hook-up unknown.</td>
<td>4. Assurance of 100% hook-up.</td>
</tr>
<tr>
<td></td>
<td>5. Detonating fuse functioning unknown.</td>
<td>5. Initiating unit functionality known.</td>
</tr>
</tbody>
</table>

TABLE I – ELECTRONIC vs PYROTECHNIC INITIATING SYSTEM

The electronic detonators provide more accurate timing than the conventional pyrotechnic detonators which rely on the combustion speed of a pyrotechnic composition.

2. RESULTS

2.1 IMPROVED FRAGMENTATION

Fragmentation results can be analysed through software packages such as Wipfrag or Split. This analysis will deliver results in terms of relevant fragment sizes, or the improvements thereof. However, there was no need to prove improved fragmentation, it was visually evident.

Management took a decision to rather investigate the resultant effect of improved fragmentation i.e. improved dozer and dragline productivity.

Dozer and dragline productivity’s form part of the day to day operational controls, thus it would be easy to track trend movement on them. In terms of measurement procedures it would place the results in perfect correlation with previous results.
Figure 1 shows how the D11 Dozer Fleet performed over a period of 12 months (2000/2001 Financial Year). Currently the dozer productivity average at 432 BCM's/Hr. The average for the previous financial year was 368 BCM's/Hr. The current performance constitutes a productivity improvement of 17.39%.

Figure 2 indicates what happened with the average productivities of Marion 2, 3 and 4. The graph shows a gradual increase in the average TCM's/Dig Hr. The average TCM's/Dig Hr improved from 1695 TCM's/Dig hour to 1834 TCM's/ Dig hour. This constitutes an improvement of 8.20%.

FIGURE 1 – DOZER BCM’S/HOUR

FIGURE 2 – DRAGLINE TCM’S/DIG HOUR
Table II summarises the various productivity improvements obtained. All the benefits relates to improved and consistent fragmentation results.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dozer Productivity (BCM’s/Hr)</td>
<td>368</td>
<td>432</td>
<td>+17.39</td>
</tr>
<tr>
<td>Cycle Times (M2,3&amp;4) (s)</td>
<td>75.36</td>
<td>70.76</td>
<td>-4.60</td>
</tr>
<tr>
<td>Dragline Productivity (TCM’s/Hr)</td>
<td>1695</td>
<td>1834</td>
<td>+8.20</td>
</tr>
</tbody>
</table>

**TABLE II – PERFORMANCE COMPARISON**

### 2.2 REDUCED DRILLING REQUIREMENT

In the past Optimum Colliery was drilled and thus blasted inventory constrained. This implies that there was not enough drilled inventory in the field.

During Stages 2 and 3 of the implementation process the drill patterns were increased. Table II shows the changes made on interburden patterns (Marion 2,3 and 4) and the effect it had on the drilling requirement for a 300m block.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-split Spacing (m)</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Stand-off from pre-split (m)</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Burden (m)</td>
<td>7</td>
<td>8.3</td>
<td>10</td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>A-line spacing (m)</td>
<td>7</td>
<td>8.3</td>
<td>9</td>
</tr>
<tr>
<td>Stemming length (m)</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Number of rows</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Number of holes</td>
<td>285</td>
<td>233</td>
<td>196</td>
</tr>
<tr>
<td>Percentage change relative to Stage 1</td>
<td>-</td>
<td>-18%</td>
<td>-31%</td>
</tr>
</tbody>
</table>

**TABLE III – DRILL PATTERN CHANGES**

Figure 3 indicates the subsequent improvement in blasted inventory.
2.3 REDUCED EXPLOSIVE COST

By increasing the drill pattern the number of holes in a blast block are reduced. This implies a lower powder factor i.e. less explosives per cubic meter of waste material.

Table IV illustrates the cost impact of increased patterns on a 300m interburden blast block.

<table>
<thead>
<tr>
<th>Pattern</th>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of holes</td>
<td>7 x 9 x 7</td>
<td>8,3 x 10 x 8,3</td>
<td>10 x 11 x 9</td>
</tr>
<tr>
<td>Explosive kilograms</td>
<td>226 692</td>
<td>172 519</td>
<td>126 251</td>
</tr>
<tr>
<td>Powder factor</td>
<td>0,76</td>
<td>0,56</td>
<td>0,43</td>
</tr>
<tr>
<td>Accessories cost</td>
<td>R17 308,65</td>
<td>R30 084,14</td>
<td>R22 906,12</td>
</tr>
<tr>
<td>Explosive cost (R1,67)</td>
<td>R378 811,88</td>
<td>R288 286,10</td>
<td>R210 970,77</td>
</tr>
<tr>
<td>Total blast cost</td>
<td>R396 120,53</td>
<td>R318 370,24</td>
<td>R233 876,89</td>
</tr>
<tr>
<td>Unit cost</td>
<td>R1,33</td>
<td>R1,07</td>
<td>R0,79</td>
</tr>
<tr>
<td>% Reduction (relevant to Stage 1)</td>
<td>-</td>
<td>-20%</td>
<td>-41%</td>
</tr>
</tbody>
</table>

TABLE IV – BLAST COST REDUCTION

The actual impact of implementing electronic detonators is not quite clear when we look at the actual performance against budget. There were a few factors that impacted negatively in terms of blast cost. These events clouded the positive cost effect achieved through electronic detonators. During the 2000/2001 financial year the implementation of electronic detonators realised an actual cost saving of R10 251 182 or 17,18%.

2.4 REDUCED VIBRATION AND AIRBLAST

The use of electronic detonators necessitated a revision in the blast timing requirements to conform to stipulated levels of vibration and airblast. Subsequently a downward trend was observed in the following monitoring criteria:

- Amount of triggered events.
- Vector sum measurements.
- PPV measurements.

Figure 4 indicates a steep downward trend on the total amount of triggers per month. Optimum Colliery has 20 mini seismograph units stationed around the property. The trigger levels are set as follows:

- PPV: 1mm/s
- Airblast: 120 dB
FIGURE 4 – PPV/AIRBLAST TRIGGERS

Figure 5 depicts the average vector sum of measures per month. The trend is noticeably downward.

FIGURE 5 – AVERAGE VECTOR SUM MEASUREMENTS

Figure 6 shows what happened with the average PPV measurements per month.

FIGURE 6 – PPV MEASUREMENTS

The use of accurate electronic delay detonators has lead to a definite reduction in vibration and airblast occurrences as well as their relative impacts.
3. **BLASTING SAFETY**

The implementation of electronic detonators at Optimum Colliery started with a detailed risk assessment. Various suppliers and relevant experts were involved with the risk assessment. During this process all the possible relevant risks were identified. Subsequently, the controls as they apply as mitigation of the risks were identified or designed. The mitigation of the risks constituted in relevant design features as well as operational procedures and instructions.

The main issue surrounding the usage of electronic detonators, is the presence of electrical current on a blast block. This aspect has been addressed through the principle of inherent safety.

There are other possible impacts or influences that might affect system safety. Most of these impacts of influences are also relevant to pyrotechnic detonators. Rigorous tests are conducted on relevant aspects to ensure safe operation.

Technology has been applied to ensure safe operation. There are however a second dimension to the usage of the system i.e. the user. Certain procedures and work instructions have been designed to ensure safe application of the system. These should be adhered to. Through the combination of design features, operational controls, and training the usage of the electronic initiating system is rendered safe.

4. **CHANGE MANAGEMENT**

Change is imperative for any business in the modern competitive market. Change, however, always brings about resistance. The process of effective change management will lead to minimal negative impact on a business.

The implementation process of electronic detonators at Optimum Colliery was successful. However, there are a few areas where a different approach might have improved the process. The major one being the involvement of relevant people at all levels as to ensure proper buy-in in the process. With adequate buy-in the process will have a team effort approach rather than a top-down management enforcement one.

Employees at operator level resisted the change of blast initiating systems at first. But after witnessing the benefits of the electronic system, total buy-in was achieved. From this stage the change process had to be directed as supposed to be enforced.

5. **CONCLUSION**

Explosive energy has to both break and displace the rockmass in which it is applied. Its effectiveness is directly proportional to the effective burden the energy must overcome. This relationship is crucial in basic blast design. Any variation in hole detonation timing that would result in a hole being fired prior or after its nominal firing time will result in burden to energy relationships that will have adverse effect on blast performance.

The pyrotechnic delay elements do not provide the timing accuracy necessary to consistently and measurable mitigate the adverse impacts.

Within the last 10 years, various groups have produced and studied the use of high accuracy electronic detonators. These studies concluded that accurate hole detonation would effectively minimise these adverse timing related impacts.

Test data verified the electronic detonators in terms of delay accuracy, their potential to reduce ground vibration and their positive impact on rock fragmentation and subsequent productivities. The timing accuracy capability of the electronic detonator allows for:

- More efficient application of explosive energy.
- Improved rock fragmentation and size uniformity.
- Excavation productivity increase.
- Cost saving on excavation and downstream operations.
- Improved public acceptance to blasting.
The implementation sites of electronic detonators represented small quarry operations mainly in the USA. These sites were all more or less ideal test sites. Optimum Colliery is one of the largest opencast operations in the World. This environment did not cater for test site specifications and procedures. Electronic detonators had to be implemented among the reality of the day to day production operations and pressures.

The main implementation objective was to reduce explosive consumption, thus costs, while not impacting negatively on production in any way. This forced an implementation approach of caution. The implementation of the electronic detonators at Optimum Colliery was successful and proved to be hugely beneficial.

Based on the same blasting parameters as pyrotechnics, the use of electronic detonators improved the fragmentation dramatically. A visual inspection only was enough to confirm the improvement. The improvement relates to the rock mass being broken into smaller pieces. The results are being achieved on a more consistent basis as well.

With cost reduction as primary objective the powder factor was lowered. The powder factor was reduced by opening up the drill patterns. The patterns on the interburden benches was opened from a 7m x 9m to a 10m x 11m burden and spacing. On most overburdens the burden and spacing were increased from 7m x 9m to 8m x 10m.

This implied that the drill requirement had been reduced. Less linear metres had to be drilled for the same blasted cubic metres. On the interburden benches the drill requirement reduced by 31% and 18% on the most overburden benches. The reduced drilling requirement allowed for a reduction in drill fleet size. The number of drills in operation was reduced from ten to eight.

Because of the drilling process being more efficient, the blasted inventory was increased from 1.7 million cubic metres to over 3.0 million over a twelve month period. This implies more efficient subsequent dozer and dragline operations.

The more efficient application of explosive energy catered for a reduction in explosive consumption. This constituted in huge cost savings. The blast cost on interburden bench was reduced by 41%. This is after the rise of 71% in accessory cost per hole has been taken into account. On the overburden where patterns were increased, a cost saving of 20% was achieved.

When analysing the actual cost performance against budget parameters for 2000/2001 the total saving is however only 17,18%. The positive effect of electronic detonators on blasting costs was impacted upon negatively by huge explosive price increases and changed mining methodologies which incorporated higher powder factors.

The implementation of electronic detonators also had a positive effect on the dozer performance. Through the combination of improved fragmentation and retraining, the dozer performance increased from an average of 368 BCM's/HR during 1999/2000 to 432 BCM's/HR during 2000/2001, an improvement of 17,39%.

The most critical aspect of dragline productivity is cycle times. With better fragmentation the bucket fill time was reduced with the obvious reduction in cycle times. The cycle times for Marion 2, 3 and 4 reduced by ± 5 seconds or 4,60%.

When the individual cycle times are reduced it implies more cycles per hour. More cycles per hour implies more waste material being moved per hour. The TCM's/Dig Hr for Marion 2, 3 and 4 increased from 1695 TCM's/Dig Hr during 1999/2000 to 1834 TCM's/Dig Hr in 2000/2001. This constitutes a dragline productivity improvement of 8,20%.

Optimum Colliery achieved the highest coal exposure of its history during the financial year 2000/2001. A total of 18 013 508 tons of coal were exposed. When taking into account that Marion 3 was down on a major breakdown for a month and one small dragline was doing rehabilitation for six months, the exposure performance was excellent.

An additional benefit of electronic detonators is the improved control of blast-induced vibration and airblast. Over the period stretching from April 2000 to April 2001 the following related improvements were realised.
- The amount of triggers (vibration and airblast) was reduced from an average of ± 40 per month to ± 10 per month.

- The magnitude of vibration events expressed as a vector sum measurement reduced from an average of ± 2.3 mm/s to ± 1.8 mm/s.

- The actual PPV measurements reduced from ± 13 mm/s to an average of ± 6 mm/s.

The implementation of electronic detonators at Optimum Colliery as a process was successful. However there are a few areas that might have been approached differently. The most significant being the involvement of all stakeholders. This promotes buy-in, acceptance and ownership.

The benefits of electronic detonators have been proven on various small sites. These same benefits are reaped at Optimum Colliery, a large full scale production environment.

The electronic detonator technology has been long awaited. It is the quantum leap of the blasting science. This breakthrough will assist the mining industry to achieve more efficient blasts, which relates to cost reduction, increased productivity and reduced residual seismic levels. This technology will be embraced by many other operations as well.

REFERENCES