

# **With Compliments**

# Nine Years of Blasting Experience with Electronic Delay Detonators

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# 1. Abstract

AEL has been developing electronic detonators continuously since 1986. It launched its first system for opencast mining in 1993, and now has two distinct product lines. The path has not been without great difficulty, but the determination to persevere was always buoyed by the strong encouragement of customers who experienced the transformed blasting results, as well as a clear vision of the enormous intrinsic value of the concept.

The path of growth to dominant global supplier is traced through the separate application channels of coal stripping, quarrying, massive mining, opencast mining and narrow reef mining, to the first all-electronic detonator demolition blast in June 2001. Reasons for the slow coming to market of this highly desirable concept, which often coincide with reasons for the demise of various other systems, include the difficulty of safely mating electronics and explosives in a low cost environment; the extreme difficulties of achieving proper connection under mining conditions; the rapid rate of evolution of the technology, and the safety concerns raised by various accidents and incidents along the way.

ED's are now established as the way forward and are set to displace other systems in all serious applications. There is place for both programmable and pre-set delay systems.

# 2. Introduction

The race to develop a commercial electronic detonator (ED) probably dates from the 1983 ISEE meeting in Dallas, at which Paul Worsey presented a paper on the concept. A number of groups, including ICI Explosives (of which African Explosives Limited was an associate company) were working on them, but a consciousness of rivalry began from that time.

It would be a few years before production detonators became available, and in the meantime there was keen debate as to whether there would be real merits in the technology. High among the attributes under debate was that of precision: it was generally acknowledged that pyrotechnic delays suffered from timing scatter, but a sizeable constituency felt that they were good enough: after all, paper after paper at explosives conferences dwelt on how precise the pyrotechnic delays were getting, and what good control was being achieved over blasting effects.

High on the expectations of the ED systems were that they would be ultra safe, owing to the ability to code the firing circuit to only recognise secure signals. They would also be cheap, because of the high volumes of electronic chips consumed in blasting. In addition, the blasters would welcome the ability to check out the readiness to fire, and fix any faults.

The ICI group developed an electronic detonator system and trialled it extensively between 1987 and 1989. It mimicked electric detonators in being given a predetermined number, with 64 delays available, and the interval between the delays being determined by the blast controller. The system was used for some key internal trials to determine both the potential of precise timing, and the ability to track changes in blasting results under tightly controlled conditions (Beattie, Grant, 1989). However, in view of the obviously better potential of the South African detonator, development of this system was shelved in favour of programmability.



In South Africa, the narrow reef gold and platinum mines were using well in excess of 200 million capped fuse units per year – over a million per production day – and there was general agreement that misfires and out-of-sequence firing with these units was causing significant losses for mine owners. With such a large user base, and the active innovation and technically advanced culture brought about by the sanctions of the Apartheid era, three separate South African groups committed resources to building ED's: Altech, Plessey and AEL, the latter in co-operation with ICI Explosives. The Plessey system was later adopted by Sasol Mining Initiators, SMI, and this remains a contender in the market place.

In the event, the challenge of producing a detonator that could be fired safely and easily by a microchip turned out to be a great deal harder than had been anticipated. The key reason was probably that the electronics experts took time to connect with the conditions in which the systems would have to work. People not exposed to the harsh realities of mining could hardly anticipate how technologies that worked for automobiles and industrial electronic appliances would be completely inadequate once explosives, rock and mining pressures were involved.

It took AEL seven years from launching its Expert Explosives project in 1986, to offering its first product to the mines. By this time the vision of a cheap system had evaporated, not only with the cost of seven years of intensive development work, but also with the realisation that non-negotiable expense is tied to the strong, high quality components required for the safety and robustness issues. This resulted in a time of hard thinking: if the system was too expensive for narrow reef applications, then the high volumes upon which the concept had been launched could not be tapped. It was quickly evident that the units should be introduced to mining applications in which the cost of the units was minimal relative to the volume of rock moved, and the benefits of using them would handsomely repay this investment.

This in turn focussed attention on proving that there would indeed be benefits from the accurate timing, and three key, innovative customers who had shown great interest in the ED development became the proving grounds for what was launched as the ExEx 1000 Electronic Detonator system. These were, Arthur Taylor Opencast Coal Mine, Kleinkopje Opencast Coal mine in the Witbank coal fields, and the underground operations of De Beers Consolidated Mines at Limeacres and Koffiefontein.

# 3. The ExEx 1000 System

The system has been described in previous publications (for example Hustralid, 1999) and is no longer extant, but knowledge of its characteristics is necessary for understanding the evolution of the system.

The detonators were programmable via a Blast Controller, either by means of a keypad, or from a software package running on a laptop PC. The Controller could fire up to four separate circuits at once, each containing 200 detonators. During the testing phase, a green key ensured that safe voltage was applied to the firing circuit. Once ready to fire, a red key was inserted and the system went into blasting mode.

The order of connecting each detonator to its harness was the key method of identification, so it was vital to represent the drilling pattern and the path of each harness through this accurately when deciding on the timing pattern and constructing the table of delays.

The wiring harness consisted of a five-core ribbon cable, one core being a series connection through every detonator. This was achieved by crimping the six-wire detonator downlines onto the ribbon cable, the fifth and sixth wires forming the up and down wires from the detonator to the series wire. In crimping, the series wire was clipped and each side attached to the detonator down and up lines – hence the system was known as a 5/6-wire series system. Crimping required the use of a special crimping tool, which acted on the block connector of the detonator, forcing six sharp clamps through the harness and making the required connections.

Despite the huge development effort, the system was very primitive at this stage, relative to what it would become. An exceptionally steep and painful learning curve lay ahead.



# 4. The First ED Production Shot at Kleinkopje Coal Mine

The very first blast was taken at the Kleinkopje opencast coal mine on 10 June 1993. There were 80 holes of 311mm diameter and 25m deep, on an 11m x 11m pattern, and loaded with ANFO. The deep holes were primed with two ED's, backed up by a single shock tube unit: three primers in the hole. Another 59 satellite holes were drilled only 8m deep between the main holes to deal with the strong surface sandstone capping.

After 7 years of intensive development and testing expectations were high. The blasting time was set for 14:00 but when we arrived at about 11:00, expecting to find most of the holes connected and ready, we found a worried air, and the development team guys running up and down the blast in their mining boots, with the blazing sun bringing out heavy sweat. It turned out that they were experiencing inconsistent signals from holes which had been connected and which had reported in as correct, but which later changed to troubled condition. This syndrome was to become an enduring challenge in the years ahead, and was dubbed "Ghosting", as it was very difficult to pin down the problem. The two main causes of Ghosting were, (a) insufficient grease in the connectors to drive out moisture and oxidation of joints, and (b) the drop in voltage resulting from low voltage signals having to travel over thousands of metres across the blast and down holes. On this small blast, 4.5km of wire had been used, and the problem cleared up when the harness was divided into two, enabling a stronger signal at each node. Large tubs of grease became essential aids to making the system work, and the electronics team invented "turbo-talkers", which were booster stations inserted in the blasting cable to lift the strength of the signals. The hard truth would be driven home time and again: it is almost impossible to anticipate field conditions, and only in real blasting situations can electronic systems be properly bedded down.

The customers were highly intrigued at the goings on, and were phlegmatic when, having twice postponed the firing time, we decided to take the blast the next day when we would return with supplies of grease, spare connectors, extra crimpers and additional batteries. Entering the blasting pattern onto the computer was not as easy as we had hoped, because a lot of the short "satellite" holes had not been drilled in good alignment with the main pattern; also, the pattern was fairly irregular along the free face and the interface with the previous blast. It was a challenge to accurately represent the juxtaposition of all these holes, and the path of the harness wires, and assign appropriate delays: however, there was a thrill in being able to dial delays in steps of a millisecond and cater for the anomalies. When encountering a malfunctioning detonator, we added an extra detonator to the harness and timed it to initiate the back up shock tube detonator at the correct time.

Eventually the blast was connected up and ready at 15:30 - much later in the day than we would have liked, and with an alarming percentage of malfunctioning detonators. We fired the shot, and full scale blasting of electronic detonators in opencast mining had arrived in South Africa.

The results of the blast appeared to be excellent: more movement than had been achieved with the pyrotechnic blast next to it, and lower vibration levels. It would be some time before the dragline tested its digability, but mine management were very supportive. Despite the delay in blasting time, we began a test programme at the mine that was to extend for two years.

#### 5. Learning Curve at Arthur Taylor Opencast Mine

The greatest learning curve took place at the Arthur Taylor strip mine in the same area. This produced 340000 metric ton per month of export coal, stripping over 1 million Bench Cubic Metres of ultra hard sandstone to expose it. Production was from one dragline, in one 50m cut of 3.5km length. Lying in the very centre of the coal reserves and fast being approached by the single cut, was a large bank of grain silos which had to be preserved intact as long as possible so that the farmers could harvest their crops and send the proceeds out before the silos were demolished to make way for the pit. The requirement on the part of mine



management was that their very high productivity should be sustained without damaging the silos, blasting weekly. In addition, a critical rail bridge skirted the border of the mine concession area, and vibration control was needed in this area. Vibration monitoring had been undertaken at the site, so there was a history upon which to build (Ladds, Jordan and de Graaf, 1996).

250 mm blastholes were charged with Powergel P700 (a 35/65 AN/Emulsion blend), and the tough sandstone overburden, which varied from 20 to 30m depth, was drilled on a graduated, nominal 7m x 8m pattern. The dragline method in use called for a muckpile level with the highwall, so timing was oriented to progress the blast parallel to the highwall, with 110ms between rows and 25ms between holes.

A strong technical liaison team was set up between the mine management and AEL, and we initially timed the blasting identically with the pattern for shock tube systems. However, we greatly increased the level of monitoring, placing vibration sensors not only at the base of the grain silos, but at the middle and top of these concrete structures, and in the ground at 50m, 100m and 200m from the silos toward the advancing cut. The most useful vibration technology for this turned out to be a locally developed Dataseis system by TLC software, which consisted of a docking station, attached to a laptop computer. The docking station could take 16 channels of vibration, enabling five separate three-vector records to be captured at once and compared with the same time base. Built-in analysis software provided the ability to review frequency.

A series of eight large electronic blasts was taken between October and December 1993, which brought both excitement at what was achieved in terms of dragline productivity and vibration control and alarm at the real problems encountered (Cunningham, 1994). Among the key learning points were:

- We established a strong relationship between intershot timing and control over frequency. Holes fired close together did not show timing-frequency control but rows fired more than 50ms apart created ground frequencies which were the reciprocal of the delay (100ms yielded 10Hz). This was very effective in controlling the amplitude of vibration in the silos, which had resonance at 2.5Hz and 8Hz. By fixing the inter row delay at 65ms, a ground frequency of 15.5 Hz frequency was generated, which translated into very low amplitudes in the silos. The linkage between timing and frequency was however lost where either there was a blast malfunction, or there was an intrusion of soft earth.
- We attempted to harness vibration prediction software using seed waveform from a single hole to simulate the overall vibration signal from the blasting. This exercise was spectacularly incorrect, and since this was the only situation, in which the actual timing matched theoretical timing, confirmed in the mind of the author his suspicion that this kind of modelling has limited validity.
- The digging rate of the dragline accelerated significantly with precision timing. The standard rate was 1650 TCM, but the minimum achieved with ED's was 1900 TCM. This increase resulted while the powder factor was lowered to 0.61 kg/m<sup>3</sup> from 0.75 kg/m<sup>3</sup>.
- The dozing work reduced by 67%, enabling what had previously taken 3 days to be done in 1 day through improved profiling of the muckpile.
- However, two very poor blasts resulted. In one, the blaster accidentally connected the blast controller to the wrong end of the harness wire, which caused the back row to fire before the third and fourth rows. This resulted in a huge ridge of strong but badly cracked ground, which had to be worked away at considerable cost. This highlighted the problem that with electronic detonators, unlike shock tube systems, it is not always obvious in which direction the blast is going to initiate.
- In the other poor blast, the mine engineer harnessed the flexibility of the initiation system to extract a 70m deep V-cut into the bench, then commence a long conventional blast



using this as a free face, in one shot. In this case, a huge raft of solid rock was left with fragmented rock underneath. Analysis indicated that the impact of cutting the V shifted the strong surface layer, so that the upper regions of the charges were cut off from the column charges. A principal we learned from this was that in hard, horizontally layered rock, the cut should not be taken at the same time as the panel blast, as the energy and time to eject this rock gave opportunity to be dislocated. Up to this time we had been using one primer per hole, backed up by a shock tube primer in case of malfunction when testing. Henceforward we adopted two ED primers per hole to ensure that the troublesome top capping of the overburden would be fragmented in the event of ground shift. Two back up shock tube detonators were also therefore used, resulting in four primers per hole.

- One of the supposed benefits of the system, that it identified malfunctioning detonators prior to blasting, proved to be somewhat of an annoyance to production personnel, as it could mean delays in trying to fix problems. With the shock tube systems, because there was no indication that a malfunction was imminent, there was no angst to deal with. Misfires would be tomorrow's problem. Thus the perception arose that the malfunction rate with the ED's was high, and that shock tube units were absolutely reliable. In fact, what was causing much of the malfunctioning was the action of stemming the blastholes prior to blasting. The techniques employed, which varied from shovelling drill cuttings by hand to using tractors with adapted hydraulic arms to gather the cuttings into the blastholes, resulted in severing of one or more downlines. During diagnosis, it quickly became evident that the back up shock tube units were just as likely to be severed, and by drawing the attention of management to this, the situation was partly alleviated.
- The Ghosting problem was particularly troublesome in deep, wet blastholes, and called for massive and unsustainable back up from service staff. In what was to be the last blast for months, a very large shot at the end of the pit on the last day of 1993, with the dragline standing and waiting for the connecting to be completed, with heavy rain, we were unable to solve the ghosting before darkness fell. We called out the ExEx development team to complete the connection process overnight, and shortly before midnight, while communicating by radio from one blasthole to the person on the blast controller, the blasthole, containing 1.3 tons of high explosive initiated, breaking out to the 30m high face and taking with it two blastholes in front of it. Miraculously, our man, who was thrown 5m into the air, landing just on the safe side of the void, was not seriously injured. However, this was the last straw, and a halt was called to implementation of the system everywhere. The blast was fired using the shock tube back up units, and the mine reverted to this system of blasting, albeit using a much enhanced method of timing learnt from the electronic timing.
- This event brought home in the most dramatic way possible that all technology is fallible. As a result we developed and adhered to the principle of Inherent Safety: until the shot is cleared for blasting, no electronic detonator may be tested with any voltage capable of firing the bridgewire, assuming that this voltage was applied from a capacitor directly across the bridgewire and with no intervening electronics.
- The reason for the early firing of the detonator was attributed to the fact that there had been severe leakage conditions, and under these it was found possible for the testing signals to be channelled to the firing circuit, allowing the capacitor to be charged. Under this condition, it was relatively easy for a triggering signal to be inferred from the radios being used for trouble shooting. In trying to establish continuity the circuit had time and again been powered up, and confidence in electronics had resulted in full system power being available during testing. After this, on-bench testing was executed with 3 Volts, since testing proved that no firing could occur below 5.2V.

This accident necessitated a rethink about whether we were in the right business, as:

• We were confronted with a massive safety concern,



- We were a long way from making any money: a large investment had been sunk in development, and it was clear that a lot of work still had to be done,
- The cost of the personnel needed for trouble shooting in order to sustain blasting operations were prohibitive.

While we were pondering these issues, a key incident convinced us to carry on. I was on the mine assisting in implementing shock tube blasting which would simulate as near as possible what we had achieved with the ED's, when the mine manager approached me and very strongly exhorted us to keep on with the system. Considering the enormous expense and trouble of two bad blasts with the system, plus the inquiry incurred through the blasting accident, this spoke volumes for the commitment of a person only too aware of possible downsides.

In the months ahead, a major investigation and re-engineering programme was put in place, and the Inherently Safe system was taken back into the field with renewed hope. By this time the first coal operation with which we had been involved were calling for involvement, and with the limited resources it was decided to devote the onward effort at this mine, since the holes were dry and ANFO was a great deal easier on the electronic system than deep, wet holes. The urgent need was to find a way of getting an economic return on the system.

#### 6. Bench Marking of Coal Mining

A major benchmarking exercise was conducted at the Kleinkopje operation, where production personnel were convinced that the few trial blasts of the previous year had demonstrated enhanced breaking results. This exercise was very helpful in further defining the needs and refining the procedures for the ExEx1000 system, but also demonstrated two things:

- with the rapid changes in geology, contemporaneous developments in mining technology and a long lag between blasting and digging, the benefits we tried to claim for the electronic blasting tended to be disputed by others who were also seeking recognition for their presence,
- this happened at a period when mining operations were still operating under functional, rather than business focus. As a result, costs had much higher focus than operational efficiencies.

After about 18 months of close monitoring, very little could be agreed: a possible 3% improvement in dragline productivity emerged, but there were ongoing questions about the reliability of the dragline monitoring equipment, and the project was dropped. Valuable experience had however been gained in making the ED system work, and in understanding the vulnerabilities.

At another coal mining operation, again with extremely hard sandstone, the proposal was made to attempt to do shoot simultaneous production and splitting of the high wall. This would enable the splitting and production drilling operations to be conducted together, resulting in much improved productivity. However, this turned into another catastrophic blast, because the mine refused to pay for putting two ED's in every hole, and the sales manager, against the firm recommendation of the technical engineer, insisted that using one primer would be adequate. Thus only one primer was placed in the 30m deep holes, and once more the blast caused a massive shift of the sandstone above the primer locations, with the result that huge rafts of badly cracked but unfragmented rock were left above the fragmented bottom sections. This was getting to be very expensive on both remedial work and our reputation, so it was decided to leave coal stripping for later. What we had to address were (a) ability to sell the right system with the right prices, (b) dangers in trying to lift volumes to make the business viable.

An additional valuable lesson learnt in this blast, was an unexpected initiation. This happened after the mine had been cleared, the Blast Controller had powered up the detonators, and the



countdown had begun. The investigation showed that the firing cable ran over the power feed to one of the shovels, and induction between these cables was sufficient to trigger the firing impulse to the detonators. Thus the detonators themselves were immune to radio frequencies, but the operating equipment was vulnerable once ready to fire. Although this was a relatively small hazard, it added one more procedure to the blasting instructions: no use of hand held radios within 15m of the firing circuit at any time, and the cables not to be laid across other power cables.

# 7. Massive Mining

The most spectacular achievements were achieved with the ExEx 1000 system in the 1993 - 1997 period at the De Beers Finsch and Koffiefontein diamond mines. Kimberlite is a very challenging material with which to work: it is tough enough to require blasting, but can also slump and crumble like clay. These two mines began as open pits, but are now worked as underground mines open to the bottom of the surface mine. Ring blasting delivers ore into the open area. A typical scenario which called for extreme measures arose when sections of ore began to collapse, and unless the drilled rings, normally fired one by one, were fired together, the access tunnel and ore would be lost.

The crucial capability of the ExEx detonators to be programmed to fire in steps of 1ms, up to 10 seconds, enabled large numbers of rings to be initiated with different delays for every hole, in a short enough time span that minimal cut-offs would occur. In addition, it was possible to create a controlled flow of broken rock towards the often very restricted free face.

In a series of blasts at both mines, it was conclusively and impressively demonstrated that ore could be recovered with minimal overbreak and excellent fragmentation, in situations which could not be addressed by normal blasting systems. We also confirmed that firing intervals much shorter than allowed by conventional ideas were beneficial in tight situations, if used in the right way.

The problem for AEL was that the mines saw the system as a speciality solution, and not something for routine blasting. This was mainly because of the greater cost of the system.

# 8. Quarrying

The vibration consciousness of quarrying operations was gradually escalating in the latter half of the 1990's, and it became very evident that amplitudes were typically reduced by at least half simply by converting to ED's. However, at Peak Quarry near Cape Town, the management took a particular interest in the possibility of controlling fragmentation (Cunningham C V B, Bedser G and Bosman H G: 1998), as they needed to change the product split coming from the mill. In a process commencing in 1996 and still underway, they converted their entire blasting process to ED's, and managed to lift production of their needed sizes, as well as increasing the loading rates, truck loading capacity and mill throughput. Complaints from surrounding domestic areas virtually ceased. This was the first operation to convert fully to ED's for production.

# 9. Evolution of ExEx System

It was recognised already in 1993 that the ExEx 1000 system had shortcomings that would have to be addressed. As time progressed, the needs of the new, second generation system became very clear: electronic detonator systems use low voltage communications over long wiring paths in tough physical conditions, and each system is only used once. Robustness, contained cost and simplicity are paramount.

A key specification for the new generation unit was that it should use simple, low cost twin harness wire, with easy, non-polarity sensitive connection. It was also required that in the



event of a unit malfunctioning, the user could choose to blast the rest of the holes without attempting to remedy or disconnect it.

In view of the recognition of the high cost to AEL of maintaining sales of the ExEx 1000 system in the field, it was realised that the old system would be better utilised for proving the concept of electronic detonators, while major effort was directed into developing the two wire system, which was eventually to be branded as the Smartdet<sup>®</sup> system. After the expected period of teething problems, this system became fully operational during the year 2000, and is now in routine use at several major mining operations in Africa, with little intervention from AEL personnel. This testifies to the success of the team in negotiating and benefiting from the learning curve.

In particular, massive improvements in mining efficiency resulted in major mines such as the following converting over to the Smartdet system for routine production blasting; De Beers Venetia opencast mine, De Beers Finsch underground mine, ISCOR Rosh Pinah underground zinc mine, Ignore Optimum coal strip mine (Hough J, 2001); Damang opencast gold; others are in the process of converting, many quarrying operations have converted, and a number of significant underground mines are utilising the system for specialised operations (such as opening undercuts or capital development) while assessing it for more routine rockbreaking. At every mine, to a greater or lesser extent, throughput has been increased, drilling patterns expanded, dilution has reduced and vibration and overbreak have come under control. At Optimum, drilling patterns were expanded by 30%, massively expanding drilling capacity, with improvements to the blasting results despite the drop in powder factor. A major consideration in operating with ED's, is knowing when double priming is necessary and sticking with it despite the cost.

The latest new application of the Smartdet system took place in June 2001, when 598 detonators were used to topple a disused Ammonium Nitrate prilling tower in Cape Town. Among the outstanding benefits reaped from the use of these electronic detonators were the following:

- every detonator was counted and checked positive by the system, providing excellent accounting, record keeping and assurance prior to firing.
- the entire final hook up was completed within an hour.
- the timing was so precise that it seemed that a layer of sized aggregate had been put down by hand in the middle of the tower after it fell, owing to the effect of simultaneous opening of the cut to both sides.
- flyrock, noise and vibration were well below anticipated levels.

It is believed that this was the first major demolition using this technology.

The conversion from shock tube systems has taken place at a significant price differential, and with an increased risk of delays to the blast time, but the radically enhanced blasting results are delivering economic benefits that make it worthwhile. In the meantime, the system continues to evolve in every area: the detonator assembly, the control equipment, the software and the understanding of how to apply this technology for continually increasing benefits. The question arises, where next?

#### **10.** Narrow Reef Mining

In looking forward, we first need to look a little back. Altech's Detonator Technologies, AEL's chief competition in ED's was focussing on the Narrow Reef market, and had adopted a radically different approach. Since the application was essentially trenching blasts, simplicity, ease of use and lowest cost were the main consideration. A unique 5 wire series system was developed between the Altech electronics group and the then South African Chamber of Mines (Dent 1994, Solomon and MacNulty 1999). The Electrodet<sup>®</sup> system was different in every way, as the detonator consisted of a clear see-through poly-carbonate body, and each unit had a 32



second in-hole delay, with a 125ms inter-shot factory pre-set delay. Alternative pre-set delays of 0ms, 31ms and 62.5ms have been optional, but to date have not been found necessary. Intended for use in hole lengths of not more than 2.0m, the objective was to minimise cost and simplify usage in an environment where the key reasons for the success of pyrotechnic systems were their low cost and ease of use. While the principle and results of blasting were attractive to the mining operations, the cost was still of concern, and the learning curve again delayed acceptance of this system well beyond what the investors had anticipated.

As with all the other electronic detonator systems, the difficulty of achieving reliability and safety while containing costs in production conditions proved almost fatal and it was eventually sold to AEL in 1998. An animated debate ensued as to whether to close down the Electrodet<sup>®</sup> facility in order to simplify the market offering and gain increased volumes of Smartdet<sup>®</sup> systems. In the end, AEL realised that there were unique benefits in the Electrodet system, and that the cost of converting the established following to an alternative could be prohibitive. Accordingly, the new system was accepted fully into the product line of the company, and sustained sales have been achieved through a process of continuous improvement and innovation with customers. AEL thus became a company in the unique position of selling significant volumes of two quite different electronic detonators.

While the main thrust with Smartdets has been into massive mining and opencast mining, they have found application in narrow reef mining with longer holes, and particularly in Platinum mines, where their greater robustness compared to Electrodets has proved to be advantageous.

The three really tough obstacles to introducing ED's to narrow reef are,

- the high cost per ton resulting from applying ED's in blastholes of 1m length and 0.6m burden,
- the harsh, corrosive physical environment, which severely challenges any electrical system and
- the unsupervised, low literacy, trouble-averse working climate which resents any delays.

After years of struggle, the economic justification is now becoming clear across the industry, systems have become very robust, and training packs are proving effective.

A weakness of the inherited Electrodet units was vulnerability to EMP (Electro-Magnetic Pulse), which took us through a steep learning curve around the conditions which foster this, and how to deal with it. In addition the whole firing infrastructure of the system is highly developed for narrow reef mines, for which the fixed delay method of operation is advantageous. It transpired however that fixed delays have niche application in opencast and surface mining operations as is discussed below.

# **11.** System Comparison Electrodets and Smartdets

#### Connection

The blast preparation operation necessarily comes towards the end of the shift, and with the gradual deterioration of any exposed electrical contacts in a corrosive environment, the last thing that is discovered, is whether there is a fault with the circuit. Miners do not take kindly to systems, which prolong their exit, and certainly do not enjoy any fault finding which holds up the blast. This factors more than any other led to delays in accepting electronic systems.

The conventional Electrodet unit is made up of the detonator unit, a five-wire ribbon cable, and a male-female connector. Typically the cable is 2.5m long, and connection is a simple process of unclipping the connector of each detonator and connecting to the next in the order of firing.

In this lie two of the merits of the system:



- the user can see in which order the holes will fire. With programmable systems, there is no way of physically knowing this, even if the operators work in an orderly way along set paths. Entry errors are possible on even the most automated systems, so looking at the cable path is not necessarily a guide to the firing sequence. This issue becomes evident in the event of any faults, and especially if the programmer loses concentration.
- The connecting up process on each series of holes can be undertaken by several people at once, operating at different places on the working face. Programmed systems can only be hooked up one at a time, by the same person, working with a programming unit. Where multiple harnesses are to be used in parallel, this enables more than one hook-up process to proceed, but it is a distinct speed advantage in some situations to be able to hook-up a series from any position and with different people, using spatial perception as the guide to sequence.

The Smartdet system has counter advantages:

- The Smartdet programmable detonators work by "log on connect", which means that as detonators are crimped onto the harness wire, the Logger (which is normally worn by the operator) automatically registers the identity of the detonator, assigns a delay to it and issues an audible signal confirming integrity. Multiple connecting might be quicker, but it only permits checking of the series circuit only once all the connections have been made.
- Smartdet units have simple crimp connectors, which bite onto a low cost, twin-twisted harness wire. This makes it very easy to work with extended distances between holes, as it simply pulls from a sling bag worn by the operator, with the ends connected to a Logger through a Row Pod memory unit. The likelihood of poor connections and the need to return to the face are minimised by this concept. However, in the harsh conditions found on mines, connections occasionally deteriorate, and then must be rectified.

The fault condition is usually diagnosed for a specific detonator, and the operator must count to this position on the harness, open the connector and attend to any problems. An advantage with Smartdets<sup>™</sup> is that each unit is physically tagged with its identity code, which is reported by the tester together with its order of connection to the harness wire. Thus the operator has a double check on whether the correct detonator fault location has been identified.

#### Training

Typically, training makes most of the difference in terms of entrenching correct procedures and ensuring fault free blasting. In South Africa, with its eleven official languages, and generally low level of literacy, the need for systems which place the least possibly strain on ability to communicate and train is perhaps as crucial as anywhere else on earth.

In this respect, the Electrodet<sup>™</sup> system is at a distinct advantage, especially as its series connection system is not unlike the normal pyrotechnic systems, which fire in the order of connection. More than any other system, Electrodet<sup>™</sup> has been successfully adopted by unsophisticated labour, through assimilating the certification programme.

At the time of writing, AEL is experiencing over 300 panels of about 100 detonators firing weekly in the deep Narrow Reef environment of its biggest customer. The support team is less involved in problem solving, than in integrating the system with mine systems, assisting the customer in expanding drilling patterns and otherwise exploiting the potential of this radical technology.

#### Simplicity

While programmability of delays is advantageous for meeting the changing needs of mines, there is a downside to it. The ability to tinker with delays calls forth the creative instinct in production personnel, which has its dangers. It also adds an extra control parameter for every detonator, which requires a high level of alertness to avoid mistakes.



Ill effects can therefore result from:

- accidentally programming delays incorrectly,
- Ill-considered delays used under pressure of time or through the influence of unsatisfactory authorities.

At the working face, with hole-by-hole allocation of delays, there is no way of knowing what a programmed delay pattern is without carefully examining the path of the cable and then downloading the delays for each connection and comparing this with what was intended. Our field records and monitoring of blasting have shown cases where detonators were incorrectly logged, for example by failing to increment a delay between holes. This problem is overcome if the control equipment includes GPS positioning of the holes and detonators with remote programming of the timing sequence by graphics driven software, but there are many situations where this will not be possible, and there are few where it is possible now.

With pre-set detonators, the initiation pattern is defined by the connection of the trunklines, and is therefore relatively easy to check. Where time and simplicity are of the essence, rather than a desire to try to tune a blast to the last millisecond, and particularly if unsophisticated labour are doing the blasting, the Electrodets have definite merit.

In view of these contrasting characteristics, it was clear that fixed delay, series connected detonators have a role to play, complementing programmable detonators in general blasting operations. With modifications currently underway, the system can be made to work with the simplicity of shock tube but achieve some of the flexibility of programmable detonators. The enhanced system is to be marketed under the name Edet<sup>®</sup>, as the higher functionality and specifications build on the intrinsic strengths of the Electrodet<sup>®</sup> system.

#### **12.** Fixed Digital Delays For Surface And Massive Underground Use

The Electrodet pre-set delay system is closely analogous to the unidelay shock tube systems widely used in almost all mining applications. Like the shock tube systems, every detonator has an identical down hole delay, and an identical between hole delay. The key difference is that with shock tube, the inter hole delay is on surface in a separate initiator, whereas it is located in the same in-hole detonator with Electrodets.

The unidelay shock tube systems can only be used sensibly in wide and deep blasts through the use of bridging delays added between lines of the unidelays, as shown in Figure 1. The way to get Electrodets similarly able to address wide and deep blasts is through the same route: providing electronic delays between each line of pre-set delays. This is the basis of what has evolved into the Edet Blasting System.

# **13.** Edet <sup>®</sup> Blasting Systems

Relative to Electrodets, Edet detonators are shock and EMP hardened. They use a 31.25 (nominal 32ms) delay increment which facilitates the automatic implementation of timing patterns by nominal 8ms: inter-hole delays of 7ms and 8ms have been shown in blasts with precise electronic timing to provide good control over blasting vibrations while delivering even fragmentation.

The default delay units will typically be 32/32000ms (32ms intershot units with the 32 000ms in hole delays), using 0ms intershot units for decked holes. This simultaneous firing of decks is favoured by some as a way of enhancing the energy delivery between decks.

The delay between lines of holes is provided by programmable Row Delay Controllers, with resulting hook-ups such as shown in Figure 2. These units are programmed remotely from the Blast Controller firing unit, to which they are linked by a two-wire cable.



The new system has not been brought to market at the time of writing, but has been extensively developed and is undergoing field tests, which confirm that the concept is a good one.

# 14. Comparison with Smartdet<sup>®</sup> Programmable Delay System

The most obvious downside with the Edet pre-set delays in a surface blasting operation, is the current limitation on inter-hole delay of 32ms, when many shock tube layouts call for delays of less than this value. Programmable Smartdet delays can be set from 1ms upwards to 20000ms in 1ms increments, and therefore are unrestricted.

In fact, by using a programmed Row Delay at the head of every column, it is possible to have shorter inter-hole delays, and the inter-row delay would then be provided by the 32ms (and/or 63ms and/or 125ms) delays behind. However, there is a loss of flexibility. The question is whether this loss is serious: if it is, then a fully programmable system is needed.

This is a case of reviewing priorities. The need for simple, easily appreciated timing systems should not be under rated, and acceptability is associated with familiarity. Current unidelay shock tube systems lead naturally into the Edet concept, so this should be more easily introduced. The flexibility of the electronic system is much greater than the shock tube system, but not as great as comes with programmable detonators: in most situations, people will live with a degree of inflexibility in order to have convenience.

As Cunningham demonstrated in 2000, there are relative limitations with shock tube unidelay systems:

- with short inter-hole delays and long down-hole delays they cannot deliver tight timing, owing to pyrotechnic scatter, and
- they have limited lag distance owing to the problem of restricting scatter in the long down hole delays.

Thus the conventional systems are hemmed in, on the one side by inability to achieve precise short delays (or even, often, sequential firing) and on the other by the liability to in-hole cutoffs when longer inter hole delays are used. The Edet System retains the simplicity of the unidelay shock tube systems, but delivers both precise inter-hole delays and a long (32000ms) in hole delay to eliminate the possibility of cut-offs.

# **15.** Suitability of Fixed Delays

Now that the blast designer can achieve predictable intervals, there is a growing enthusiasm for understanding and harnessing the effect of different delay patterns in blasting.

The greatest learning curve is in the area of short intervals, since it has not been possible to test this area properly with conventional systems, and many designs are proving that previously unacceptably short intervals are delivering enhanced fragmentation and vibration control.

In addition, because of the difficulty of achieving either flexibility or accuracy in timing, relatively little real research into correct intervals is available. Most of the wisdom is based on limited experiment and rather simplistic science.

Experience to date with AEL's electronic detonator systems has shown that in normal underground mining, the 100ms plus range of intervals is very useful, since it avoids crowding effects in situations of extreme confinement, while assuring sequential firing. Trials with 125ms intervals have shown clear improvements (relative to shock tube units with short and long period delays) in both tunnelling and slot opening blasts in massive mining (Möhle H 1999). Although much of this was achieved using programmable Smartdets, similar success is being achieved in Chile and other venues using the fixed timing of the Edet system. The most immediate payback has been in the ability to blast slots in less time and with less holes. In



tunnelling, perimeter conditions have improved drastically, less oversize has resulted, and full advance has been achieved.

These significant benefits are only what should be expected through having eliminated out-ofsequence firing and crowding. Clearly, the programmable systems will often be the method of choice: they have greater flexibility and will lead the way in uncovering the possibilities for improved breaking. However the desirable delays so discovered can then be engineered into the fixed delay systems.

It is important to recognize that the almost universal and distinct improvements being realised with electronic detonators are often achieved with intervals not greatly different from the nominal pyrotechnic timing. While visionaries have ideas of "defining the millisecond", by which they mean changing the timing within each blast minutely to match the needs of the rock, both the need for such fine tuning, and the ability to know how to address such a need in the mining environment, is questionable. Immense benefits are harnessed by merely eliminating out of sequence shots, and achieving uniform intervals. There are also some real dangers, even with precise timing, in adopting very tight timing. Part of the danger lies in the variance even in electronic delay systems, as pointed out by Cunningham in 2000.

#### 16. Conclusion

The learning curve with Electronic Detonators is far advanced, and the reality of the benefits of high precision timing has emerged from almost every application in which they have been tried. ED systems would have been in the market earlier if they had been available, but the shear technical challenge of producing a dependable and adequate system held them from the supply shelves for much longer than had been anticipated. There is a tendency to think that one ED system is much like another, but there are crucial distinctions not only in the mode of operation, but also the aspects of robustness, user friendliness, field specifications, and limitations. This applies not only to the detonator units but also their harnesses, control equipment and software packages.

With current ED technology, in normal applications, precision is hugely improved over what can be achieved with pyrotechnic systems, resulting in reduced vibration, better perimeter control, improved fragmentation and well controlled movement. However, the ability to give tight control over stress wave interactions is somewhat in doubt, especially where firing times exceed one second. There is still a steep curve ahead, which will be complicated by the evolution of related technologies, by the difficulty of trying to achieve economic pricing for small blastholes, and the need to build systems which are usable by lower technology blasting personnel.

Major progress has been achieved with safety. There were some early learning incidents on the mines, few of which involved injury, and a low level of incidents continued around the manufacturing process but it has been a long time now since anything of note. Inherently safe systems are only vulnerable in countdown mode, when by definition, the area has been cleared: conventional electric blasting is similarly susceptible. Our experience in a number of incidents indicates that radio controlled exploders or detonators should not be considered. A wireless system requires an electrical energy source within the detonator itself and the consequences of this are very serious. It has yet to be shown that radio controlled electronic microchip systems can be made both fail-safe and sufficiently robust to be economic for use in commercial blasting. Such systems are not only a safety hazard, but would be extremely dangerous in the hands of terrorists and careless users.

Connectors and connection are the Achilles' Heel of electronic blasting in production conditions, and conscientious commitment to this area is key. We have come a long way to the present, easy to use designs, and connection problems are rare when properly executed.

Together with the undeniable technical benefits of precise timing, electronic initiation systems provide the crucial link between the blasthole and mining asset resource management



systems. This closes the control loop, enhancing the ability of these systems to continuously lift the economic performance from mining assets. For this reason alone, it is hard not to believe that electronics will dominate blasting and sooner rather than later. This factor could also see blasting technology extended, and competing even more strongly against mechanical excavation methods. Mining conditions are tough, wet, corrosive and unsophisticated, yet demand the highest standards of safety and reliability.

Over the past decade the world has seen an exponential growth in the application of electronic microprocessors in everyday life. It might be imagined that it would be easy to adapt available electronic technology to the world of commercial explosives. However this is not the case.

The up-grading of electronic components such as Logic modules, software controls, timing circuits, capacitors and switches to meet these demands present major challenges. For blasting, there is another plane of difficulty linked to tough, wet and corrosive mining conditions, unprotected wiring, the making of connections by unsophisticated workers, Electro-Magnetic Pulse, detonation pressures from neighbouring holes, assembling electronics with explosive ingredients, the safety issues around the hundreds of tons of explosives in each blast, and the consequent inability to learn in the laboratory. Chip manufacturers have also been through a learning curve with us. The value of the learning we have accumulated in design, manufacture, application and safety are inestimable: the cost has been huge both in terms of finance and human stress. However, every indication points to the goal as having been achieved at last. The main challenge remains to demonstrate to wider markets the business sense of adopting this radical technology.

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#### **18. References**

Beattie T & Grant J: Electronic Detonator Trials: Bairnsdale/ Broken Hill Final Report. ICI Australia Operations Research Group B53239. 31 May 1989.

Cunningham CVB 1994 Experiences with electronic delay detonators in major production blasts. Proc. 5<sup>th</sup> High Tech Seminar: State of the Art Blasting Technology, Instrumentation and Explosives Applications, pp305-318 (Blasting Analysis International, Inc S W Allentown, Pennsylvania USA)

Cunningham CVB and Jones M 1995 Commissioning of Production Blasting with the ExEx 1000 Electronic Delay Detonator system. Proc Explo '95 Conference, pp119-126, Aus Instit. Mining and Metallurgy, Victoria, Australia.

Cunningham C V B, Bedser G and Bosman H G: 1998 Production Blasting with Electronic Delay Detonators at Peak Quarry proc. Inst of Quarrying Durban

Dent N L 1994. A precise, reliable and easy to use and cost effective electronic delay detonator. Proc. 5<sup>th</sup> High Tech Seminar: State of the Art Blasting Technology, Instrumentation and Explosives Applications, pp 775-778 (Blasting Analysis International, Inc S W Allentown, Pennsylvania USA)

Hough J H 2001: Electronic Detonators: the Future for Optimum Colliery. Proc 10th High Tech Seminar: State of the Art Blasting Technology, Instrumentation and Explosives Applications, pp305-318 (Blasting Analysis International, Inc S W Allentown, Pennsylvania USA)



Hustulid W: Blasting Principles of Open pit mining, Vol 1 pp 244-246. AA Balkema Rotterdam/Brookfield.

Ladds CG Jordan DJP de Graaf WW 1996 Overburden blasting design and vibration monitoring in the protection of surface structures. pp287-292 Proc Surface Mining 1996: SA Inst Mining and Metallurgy, Johannesburg.

Worsey P N and Tyler LJ 1993: Proc 9<sup>th</sup> Conference on Explosives and Blasting Technique, Dallas Texas, pp489-496 ISEE.



Figure 1. Use of unidelay and bridging delays in shock tube systems



Figure 2. Unidelay electronic detonator with programmed bridging delays