Evolution of digital detonators as an intelligent tool for control blasting in Indian mines

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ABSTRACT. *Since the invention of gunpowder in 1860 by Alfred Nobel mining industry was always in need of initiating devices which helps in increasing blast size, improve safety during charging & blasting operation, as well as explosive performance. From plain detonators & Safety fuse system to Shock-tube initiation system, commercial basting has helped the above cause. However, each system has some limitation regarding the accuracy of delay, safety requirement as well as complexity required regarding blast requirement of the modern mining industry. Electronic Delay Detonators have come a long way since their invention in the late 90s. They have helped blasting engineers in solving modern mining requirement of the massive blast with minimum vibration, better control on fragmentation, blasting multi-layer rock together, controlling throw & back break etc. Electronic Delay Detonators have been introduced in the Indian market mainly for Vibration controls. With increased knowledge, Indian mining industry is now ready to embrace the other technological benefits of Electronic detonators. This paper is an attempt to review the use and benefits associated with the use of Electronic detonators, evolution and future growth prospects of the same in Indian mining industry.*

RÉSUMÉ. *Depuis l'invention de la poudre à canon en 1860 par Alfred Nobel, l'industrie minière a toujours eu besoin de dispositifs de démarrage permettant d'augmenter la taille des explosions, d'améliorer la sécurité lors des opérations de charge de la poudre et de dynamitage, ainsi que des performances des explosifs. Des détonateurs ordinaires et du système de fusible de sécurité au système d'initiation du Shock-tube, le dynamitage commercial a aidé la cause ci-dessus. Cependant, chaque système présente certaines limites au niveau de l'exactitude du délai, des exigences de sécurité ainsi que de la complexité requise sur les exigences de souffle de l'industrie minière moderne. Les détonateurs à retard électronique ont parcouru un long chemin depuis leur invention à la fin des années 90. Ils ont aidé les ingénieurs en dynamitage à résoudre les exigences actuelles de l'extraction massive avec un minimum de vibrations, un meilleur contrôle de la fragmentation, le dynamitage simultané de roches multicouches, le contrôle des relances, etc. Des détonateurs à retard électronique ont été introduits sur le marché indien, principalement pour la contrôle des vibrations. Avec des connaissances accrues, l'industrie minière indienne est maintenant prête à profiter des autres avantages technologiques des détonateurs électroniques. Ce document* *tente de passer en revue l'utilisation et les avantages liés aux détonateurs électroniques, l'évolution et les perspectives de croissance future de ces produits dans l'industrie minière indienne.*

KEYWORDS: *electronic detonators, digital detonators, delay time accuracy, blasting.*

MOTS-CLÉS: *détonateurs électroniques, détonateurs numériques, exactitude du temps de retard, dynamitage.*

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1. Introduction

From plain detonators and safety fuse to Electronic blasting system, the commercial blasting has made a rapid stride. In India, mining and other industries initially took a while to accept Electronic Blasting Systems (EBS). However, more recently the Indian industry has progressively accepted EBS. With better understanding and knowledge of the recent developments in global blasting, EBS has now started being seen as a tool to improve productivity, safety and reduction in overall mining cost in India. By better understanding and utilisation of the electronic initiation systems for blasting and designing the blasts, better results in the form of enhanced powder factor, better-quality throw, improved fragmentation, reduced/controlled ground vibration and air overpressure. All these will help mine operators to achieve significantly better results and improved blast performance (Lalwani and Menon, 2016).

2. Initiation systems and its importance in blasting

In commercial blasting, a considerable amount of energy is essential to activate the high explosive. The high explosives are detonated/activated by a small capsule containing some moderately sensitive explosives that can be easily initiated by an outside energy source called detonators. Blasting agents used for charging in the blast hole are less sensitive to initiation than high explosives. To ensure the safety dependable initiation of these products is assured, the detonator is usually placed into a ampule of high explosives called "Booster", which is placed into the blast hole column of blasting agent (Lip, 2000).

The whole system used to detonate the high commercial explosive for the successful commencement of blasting operation in mines is well known as initiation system.

Any initiation system used for commercial blasting generally involves three elementary parts.

1. A preliminary source of energy.

2. A distribution network to dispense energy that carries the required energy into the individual blast holes.

3. A component that will utilise the energy received from the distribution network to activate a cap-sensitive explosive.

The preliminary source of energy is generally uses the electrically powered battery/generator called an “Exploder”, used to energize an electric cap or a heat source such as a spark generator or a match to activate the primary charge in the detonators. The primer is a packet of cap-sensitive explosive containing the detonator. Though, the blasting agents used for commercial blasting today are insensitive to a No. 8 detonator. To activate the blasting agent, the detonator is inserted into a packet/ unit of cap-sensitive explosive called “booster”, which further is inserted into the blast hole column containing blasting agents.

Blast performance is considered good when it ensures smooth excavations and better productivity keeping the safety and maintaining the environment standards. Detonation is the phenomenon of propagation of a shock wave through an explosive, which is accompanied by a chemical reaction that furnishes energy to maintain the shock wave propagation stably. The layout of holes and its drilling in the designed pattern is essential to get the desired blast performance. Whereas, the use of initiators is to transmit the initiating energy to each holes so that it may ensure:

• The order of firing holes,

• The delay to be provided between rows and columns for desired blast performance,

• The amount of initiation energy required.

With the research and development it is evident that the delay timing and order of blast holes detonation results in enhanced blast performance. Hence, precision over the detonation order of blast holes has significant impact on overall blast performance. Although, disparity in deisgnated detonation timing of each hole often results overlapping of holes. Overlapping of holes leads to adverse effect on the blast performance in the form of poor rock fragmentation, increased blast induced ground vibration levels, higher air overpressure, fly rock generation and higher process costs and operating cost.

2.1. Evolution of initiating devices

By continuous efforts made by researchers and scientists, the initiation system used for commercial blasting is continuously developed and modified to achieve better results and to enhance the safety. The evaluation of the initiating system is shown below in their chronological order (Manzoor and Choudhary, 2014).

1830 Invention of a method of electric firing of gunpowder by an electric spark patended by Moses Shaw

1831 Introduction safety fuse by William Bickford

1830-32 Development of method of electrical blasting by Robert hare.

1860-67 Invention of the first commercial detonators by Alfred Nobel .

1870 Invention of generator type blasting machine by Julius Smith.

1895 Introduction of delay electrical blasting caps using safety fuse as the delay element by Julius Smith .

1907 Invention detonating cord by Louis L'heaur in France utilising TNT.

1930 Invasion of primer charges using more stable explosive compound.

1937 Invention of Detonating cord with PETN and Millisecond interval delay caps.

1948 Replacing the generator types Blasting machines with blasting machines using capacitor discharge with better safety and more reliable power units.

1950 Delay connection system has been developed

1960 Development of non-electric detonating systems with low energy detonating cord.

1966 NONEL technology development started by Nitro Nobel.

1968 The first successful laboratory trials with NONEL initiation system.

1973 Introduced to commercial product of Non-electric delay detonators (NONEL) providing improved accuracy in timing reduced environmental impact.

1981 Introduced to Magnet system in blasting

1986 Introduction of very precise microelectronics chip based Electronic detonators by ICI(UK)

3. Types of initiation systems/ detonators

3.1. Ordinary detonators

Ordinary detonators are very basic detonators invented by Alfred Nobel in year 1860-67. These detonators contains ignition-based low explosives. They were designed mainly to utilise in commercial blasting operations. These detonators are generally initiated with a safety fuse, and used in where timing of detonation of holes in not very critical. silver azide (AgN_3) , $Pb(N_3)_2$ and mercury fulminate [$Hg(ONC)_2$] are the common examples of ordinary detonators (Cooper, 1996).

3.2. Electrical detonators

Electrical detonators are invented late in 1800 century, these are categorised into three diferent types

1. Instantaneous electrical detonators (IED)
2. Short period delay detonators (SPD)

3. Long period delay detonators (LPD).

Short period delay detonators (SPDs) are operated in milliseconds and LPDs are operated in seconds. SPDs are the type of electrical detonators that are highly used in the mining industry for the commencement of blasting operations. Also, a new slapper detonator is developed, which uses thin plates accelerated by an electrically exploded wire or foil to deliver the initial shock. It is used in mining operations.

3.3. Non-electric detonators

A non-electric detonator also commonly known as NONEL, its a shock tube based detonator designed to initiate explosions with shock waves, generally these are used in the blasting of rock in mines and quarries. The shock tube is a hollow plastic tube transfer and delivers the firing impulse to the detonator leading to activation of detonators due to shock, which makes it safer than most of the other risks linked with electric current and detonators. Shock tube comprises of a thin, triple-layer tube of plastic having the innermost wall coated with a explosive material. The innermost explosive coating leads to propagation of a low energy wave same as in a dust explosion when ignited. The speed of low energy shock wave travelling along the length of the shock tube is approximately 2,000 m/s no any siginificant trouble to the outer layer of the tube. The NONEL detonators design is a patented technology, it includes the Delay Ignition Buffer (DIB) and Cushion Disk (CD) which provides accuracy and reliability in blasting applications.

Non-electric detonators were invented by the Swedish company Nitro Nobel in the 1960s and 1970s, under the leadership of Per-Anders Persson, and launched to the demolitions market in 1973.

3.4. Electronic detonators

In mining, electronic detonators have a better precision for delays with very low cap scattering percentage of around ±0.05%. Electronic detonators are evolved due to inaccurate timing of blasting using Non-electric and electric detonators. It is designed in a way to provide the precise control on timing of blast of each hole. The accuracy in timing of delay is essential for improved blast performance in the mining and other blasting associated industries. Electronic detonators can be programmed as per the requirement of blast deisgn ranging from 1 millisecond to 16,000 milliseconds with least increment of a millisecond using the dedicated programming device called the "Logger".

4. Electronic detonators

The electronic/ digital detonators are the detonators which uses the microelectronic chip for providing delay instead of chemical or electrical components. These are very accurate in there timing and are also very safe in operation.

4.1. Principle of electronic delay detonators

The electric and non-electric detonators show a very significant amount of cap scattering while blasting. The need of precision in delay timing is very much required to improve the overall blast performance in mines. Electronic delay detonator came in are detonators which can be utilised with more freedom in programming delay timing with high accuracy. In late 1900, the microelectronics chip was used to replace the pyrotechnic delay elements of traditional detonators. The use of microelectronics chip has significantly reduced the cap scattering enhancing the delay time precision. The basic principle of electronic detonator is the use of delay igniter in the instant detonator, which is same as used in case of pyrotechnic delay detonator. Whereas, in pyrotechnic detonators the delay is provided through the rate of combustion pyrotechnic element and in electronic detonator the delay time is provided using electronic circuits. Outline of electronic detonators is shown Figure 1. (Li, 2012)

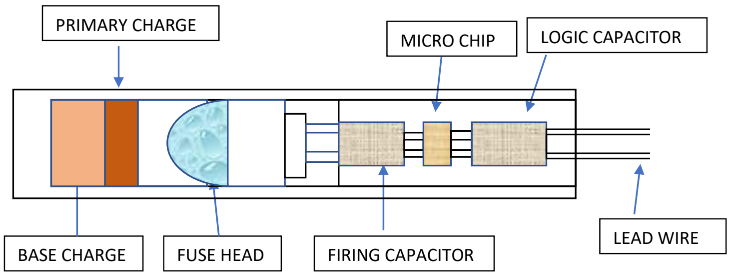

Figure 1. Outline of the electronic detonator

To enhance safety and reliability of electronic detonator, two capacitors C1 and C2 are designed in circuit to store the ignition and energy control distinctly ensuring energy required in blasting operation in the process of blasting when power lines go wrong for some reason. To improve and increased safety a switch K1 is used to control the capacitors to avoid the anti-interference, static and stray current of the electronic detonator. The main purpose is to let the system stay in the ignition state, after detection, preparing to connect, and delay time setting. However, in case of emergency if it is required to terminate blasting operation, the electronic switch K2 will quickly release energy storage of capacitor C2, which will further lead to energy loss in the detonator and will terminate the blasting operation. In regular condition, electronic switch K3 will allow the energy stored in capacitor C2 to the electronic ignition head to accomplish the blasting of electronic detonator, as per the delay time allotted. The outline of circuit in Electronic detonators is shown in Figure 2.

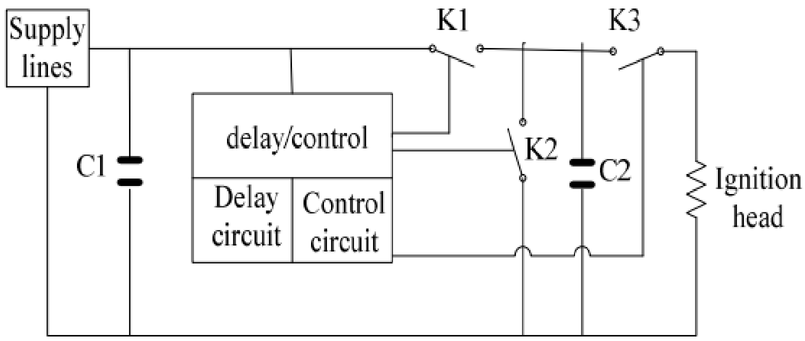

Figure 2. Working principle of electronic delay detonator

4.2. Types of electronic detonator

Electronic detonator systems based upon its use, functionality and features can be categorized into three different types as follows:

4.2.1. Factory programmed systems

Factory programmed system, in this the electronic delay detonator are assigned fixed delays from manufacturer side. The electronic detonators cannot be fired or detonated using conventional firing devices (also called “Exploder”). In each electronic delay detonators a unique firing code or communication protocol is assigned, which is used while firing the electronic detonators during blast. Factory Programmed Systems are further manufactured in specific types.

- Electrically wired systems, with unique wiring style and connection type,
- Shock tube system technology energizing an timing circuit within the electronic detonator.

Factory programmed systems has a fixed time of delay loaded and hooked up as standard electric or non-electric systems. Manufacturer also utilised different type of surface connector to simply wiring of detonators as per correct electrical polarity and timings in blast design.

4.2.2. Field programmed systems

Field Programmed Systems utilize electronic technology to program delay times "on the bench". This the most used type of electronic detonators in Indian mines. The field programmed systems are manufactured with unique communication protocol, system styles and hardware setup. In these systems no fixed delay time are assigned to the detonators. The field programmed system works on direct communication with the detonator (either just before firing, after loading or before loading) for the suitable delay time and consequent blast design. As per the decided blast design the timing can be allotted to the unique ID's of detonators using a device called "Logger". The timing is stored in each detonator. In general, these systems will utilize some type of electronic memory, which allows them to be reprogrammed at any time up until the fire command is given.

4.2.3. Wireless / remote blasting system

Wireless/ Remote blasting system allows blasting operations (underground mines or tunnels) by allowing the initiation of electronic detonator blasts remotely, within a safe and convenient control point mostly on the surface. This type of electronic detonators has not yet evolved in Indian mines. Wireless blasting system comprises of a Lock Box a and RBB (Remote Blast Box) which work with the digital logger and utilizes the existing communication infrastructure (Analogue phone networks, LAN, WLAN or Leaky Feeder), at the mine. This safely initiate blasts from either a designated Safe Firing Point underground or preferably from a surface coordination and control point.

4.3. Characteristics of electronic detonators

Since 1990's, due to inaccuracies and less control on delay timing in blasting the manufacturers were trying to use electronic devices for accurate delay timings. It was then tried to use an electronic set up to modify and remove the inaccuracy of delay time in pyrotechnical delay element used in electric detonators. Rresearchers conducted a large number of researches to develop the technology of electronic detonators since a decade from 1990's. After many trials and errors and hard work of researchers the design of electronic detonators was succedeed that too in different categories as mentioned above in section 2.2 of this paper. Being a succesful accurate blast initiation system futher the programmable electronic detonators has brought a revolution in blasting technology, it offered a great flexibility in delay time selection, initiation timinig and blast designing. The freedom to choose the delay timing together with accuracy opens doors for designing of small delays with initiation in complicated situatuon possible which is also demonstrated as a significant benefits to blasting in mining community. With such a huge number of possibilities in the design of their shots in an effort to improve blast peformance different numerical simulation softwares and tools have been developed to help mining engineer's research.

In India, despite a higher market price, electronic detonators are still under spread in market. Also, with increasing knowledge, utilisation and positive outcomes of electronic initiation system, this is getting more and more popular in Indian mining industry. Presently, only 4 manufacturers are active in the electronic detonator market in India (Table 1). Each brand uses it own programmed detonators which can be detonated only by its unique designed blaster or blasting machine. Due to a uniqueness in communication protocols of each manufacturers, blasting machines of another manufacturer cannot be used to initiate other manufacturer's detonators. Also, none of these detonators of different manufacturers can be used in a single blast shot (Philippe Dozolme, 2008). Electronic detonators are electrically wired to conduct the initiation signal energy source (Julijan Bratun, 2011) .

The characteristics or important features of an electronic detonator include:

- The Electronic detonators initially has no initiation active energy of its own.
- The detonators can be programmable from 1 to 16000 milliseconds in minimum of one-millisecond increments with precisely control blasting.
- The detonator carried a unique activation code which can be activated with a specified logger and blasting machine only, which makes it way safer.
- The initiation energy and activation code is transferred to each detonator only when logger is attached from a blasting machine synchronized with detonators unique code.
- The detonator is equipped with fusing system for over-voltage protection.
- The short delay time between two adjacent period numbers (equal to the shortest interval -time) is 1 ms.
- The maximum number of detonators connected to each blasting machine is about 1600, which makes a massive blast possible with enhanced accuracy in timing.
- In terms accuracy, the electronic detonators cap scattering percentage varies around ±0.01 to ±0.05 for any programmed delay period, whereas the shock tube initiation systems show higher cap scattering percentage variation ranging ±10-20 percentage.
- The system has full two-way communication between detonators and control equipments (logger, blasting machine etc.).

5. Manufacturers of electronic detonators in India

Table 1. List of manufacturers of Electronic detonators in India

S no.	Manufacturer	Products name
1.	M/s. C DET Explosive Industries Pvt. Ltd. "Mayapakhar", 79, Shivaji Nagar, Nagpur - 440 010	CDET Accura CDET Optima
2.	M/s. Economic Explosives Limited, 11, Zade Layout, Bharat Nagar, Nagpur – 440 033 (MS).	Microdet -I Microdet- II
3.	M/s. Gulf Oil Corporation Ltd., Kukatpally, Post Bag No. 1, Sanathnagar (IE), PO, Hyderabad – 500 018 (AP)	e-Det e-Det ft
4.	M/s. Indian Explosives Ltd., 10A, Lee Road, Kolkata – 700020	i-kon I, II, III Unitronic 600

In last decade with the increase in knowledge of electronic detonators and getting more confidence in the technology, the trend of use of electronic detonators is increasing in Indian mining industry. Mine operators have started utilizing electronic detonators to reduce the adverse environmental effect due to blasting for better and peaceful operations. This increasing trend in demand of electronic detonators has fetched the attention of many explosive manufacturers to jump into this business. In India manufacturer of electronic detonators as per the list of authorized manufacturers by Petroleum and explosives safety organization (PESO) of Government of India with their product names are listed below in Table 1 above.

6. Advantages of electronic detonators

Many researchers such as Giraudi *et al.*, (2013), Mustapha Mohd *et al.*, Lip, (2000), Banda & Rhodes, (2005) Birch *et al.*, (2010), Manzoor and Choudhary, (2014), Cunningham (2004), Lownds and Louw, (2004), Gregg (2001), Bartley *et al.*, (2004), Bartley and Trousselle, (1998), McKinstry, Chi et al (2015), Brace *et al.*, (2004). Airaud (2004), Raina (2010), Babu *et al.*, (2013), Mishra (2013) and many others have studied and mentioned the advantages of using Electronic initiation system on blast performance as well as on its environmental impacts on their research papers. The advantages of the use of electronic detonators in blasting are:

- Reliability and exact verification of initiation network connection.
- Delay range of 1–16,000 ms with an increment of 1 ms.
- The precision of ±0.01 – 0.05% of designated/ programmed delay time.
- Better intrinsic safety features.
- Unique ID in each detonator avoids pilferage and misuse.
- Safety elements, including a unique fire control command enhancing safety.
- On-line programmability such that a single detonator may be programmed for any delay period.
- A factory programmed security code unique to the operator which will provide "ultimate security" and exclude unauthorized use.
- Interactive report back facilities for complete status and circuit check before firing.
- Multiple verifications of detonators prior each blast.
- Logging and computerized allotment of delay timing.
- Better hold on firing sequence.
- Better fragmentations.
- Vibration control with lesser Peak particle velocities.

- Freedom of frequency channelling to control the blast-induced ground vibration frequency.
- Better prediction and understanding of blast-induced ground vibration using signature hole analysis.
- Control in the air overpressure.
- Better cast blasting due to accuracy in hole delay timings.
- Better wall control blasting and pre-splitting.
- Overall improvement in mine economy including mine-mill fragmentation optimization.
- Control of over break in underground tunnels and mines.
- Lesser back break in surface mine blasts.
- Improved muck pile shaping.
- Reduced stock management – as electronic detonators are programmable, only one type of detonator is required to be stored in the magazine.
- Better controlled blasting.
- Better explosive energy utilization.

6.1. Some experiences with digital detonators in India

Digital/ Electronic detonators are costlier than the NONEL and other initiation system but still offers high flexibility in delay time programming, better control and safety. These benefits and features of electronic detonators are found to provide better blast performances in mines. With better increasing knowledge and operational efficiency of Electronic detonators, Indian mine operators have started adopting Electronic detonators as their main initiation systems. Some of the practical experiences in Indian mines are briefed below.

6.1.1. Blasting in dragline benches – Singrauli Area

The Jayant and Dudichua mines located in Singrauli area of Northern Coalfields Limited (NCL) have higher stripping ratios and uses higher capacity HEMM. The operating bench heights for draglines range from 30-45 meters and for front-end shovels 15-20 meters. The drills in use are 259mm and 317mm diameter, where 65-70kg/m and 85-90 Kgs/m of charges are in use. Detonating cord with Cord-relay system were in use for initiating charges. The outer boundaries of mines are at 700-750 meters from habitation. In recent year, it is understood that villagers started raising concerns about ground vibrations and noise levels and their apprehensions on safety, the management of NCL mines decided to conduct few blasts using Electronic detonator system, to mitigate the concerns raised by villagers. NCL management also intended to study simultaneously, whether break down-time of dragline operation comes down, using electronic detonators. The blast results using electronic detonators indicated that the concerns of villagers and break down time for dragline operation reduced(Sarma and Sao, 2016).

6.1.2 Blasting long patches in iron ore mines – Barbil Area

The Iron ore mines of TATA group located in Barbil area wants to study whether the blast size can be increased, without losing control on ground vibrations, noise and fragmentation needs, by using electronic detonators. Each mine of Tata Group, located in Barbil area, excavate around 10-15 Million tons ROM each year operating on 10-meter benches, using 165mm drills, and 4- 6 cum capacity front end excavators. The blast size ranges from the 80m to120m length. The average blast size is around 40000-50000 MT. Few blasts were conducted using electronic detonators by increasing blast block length up-to 320 meters. The blast results using electronic detonators indicated that blast block length increase helps in reducing a number of blast events, reduce mining costs as the downtime of machinery due to blast events reduces, and the set blast objective of getting good break fragmentation, minimum back break, control of ground vibrations and noise can be achieved.

6.1.3 Blasting in extremely challenging conditions in hard rock mines of hzl – rampur agucha(ra) mines

HZL –RA mine is considered as one of the largest capacity hard rock mines in the world, excavating ROM of 80-90 Million per annum. The mine has many unique features. There are many varieties of rocks like amphibolites, garnet-biotite-sillimanite-schists, pegmatites, etc., The mine lease area is limited regarding pit width and mine has reached depth's up-to 230 meters. The operating bench height of mine is 10m and the drills used are 165 mm diameter. The mines use 42 cum shovels along with 240 MT dumpers for faster rock removal without overcrowding mine with machinery. To extract such large quantities per annum, the mine conducts large to huge length blasts, controlling roll over of fragments to bottom benches. The number of benches being large (more than 21) maintaining bench slope stability, is an important issue. The mine started using electronic detonators extensively a few years back, as a tool to maintain bench slope stability, to maintain desired fragment size, to control fly rock related accidents, and to reduce back break even while conducting large length blasts. Many blasts were conducted using electronic detonators in the mines, and the blast results indicate, the set objectives of the mine like maintaining bench slope stability, control of throw, back break, fly rock, are fully met even when blast block length is larger.

6.1.4. Blasting under controlled conditions where the public/private structures are located at 60-250 meters

In India, many OC mines belonging to public sector and private sector group are being operated very close to habitation due to land lease issues. The concerns/ issues at these locations are, high cost and risk associated with stoppage of mines for few hours to few days, for the reasons of noise, ground vibrations, fly-rock etc., At many mines, work stoppages/disruption were more frequent. To mitigate these issues, the management of the mines started using electronic detonators and found from blast results, using electronic detonators that the concerned issues were largely mitigated, and mines could produce the mineral with fewer interruptions /disruptions.

6.1.5. Blasting on wider drill patterns

Mine operators, in general, would like to explore whether the additional cost incurred on electronic detonator system can be recovered without increase of blast size. We, as a manufacturer and supplier of the system, demonstrated at few locations like Limestone mine located at Kotputli, two Iron ore mines of a private company located at Barbil, that the customer can operate at wider patterns, using electronic detonator system without increasing the charge quantity. The blast results, using electronic detonators on wider patterns, indicated, that there is a scope to increasing drill patterns, without preceding benefits of fragmentation like excavator /crusher productivity.

7. Use of electronic initiation system in India

Looking at the different advantages and the ability of electronic detonators in mitigating problems in mines. Also, with an increase in environmental concern and knowledge over electronic initiation system, many mine operators in India also have started using this technology. Some of the mine operators using Electronic initiation system successfully in their mines are:

1. Lafarge India Private Limited (LIPL), Sonadih Limestone mine located at Baloda Bazar Tehsil in Raipur, Chhattisgarh. Initiation of the designed blast with i-konTM, Digital Energy Control System of M/s. Indian Explosives Ltd is used.

2. Tata Steel Limited, Ab quarry opencast coal mine, West Bokaro. Initiation of the designed blast with i-konTM, Digital Energy Control System of M/s. Indian Explosives Ltd is used.

3. Bharat Coking Coal Limited a subsidiary of Coal India Limited, in multiple Opencast coal mines. Initiation of the designed blast with Microdet-I, Programmable electronic detonators of M/s. Economic Explosives Limited is used.

4. Northern Coalfields Limited a subsidiary of Coal India Limited, in multiple Opencast coal mines. Initiation of the designed blast with Microdet-I, Programmable electronic detonators of M/s. Economic Explosives Limited is used.

5. Eastern Coalfields Limited a subsidiary of Coal India Limited, in multiple Opencast coal mines. Initiation of the designed blast with Microdet-I, Programmable electronic detonators of M/s. Economic Explosives Limited is used.

6. Hindustan Zinc Limited, Rampura Agucha zinc mine, Rajasthan. Initiation of the designed blast with i-konTM, Digital Energy Control System of M/s. Indian Explosives Ltd is used.

7. Neyveli Lignite Corporation India Limited, Tamilnadu, India. Initiation of the designed blast with i-konTM, Digital Energy Control System of M/s. Indian Explosives Ltd is used.

8. Conclusion

Digital detonators have been proved very efficient regarding enhancing the performance of blasting. The accuracy, precision, flexibility and methodology of electronic detonators offer enhanced safety, improved productivity and lesser environmental impacts. The improved productivity is in the form of fragmentation control, extraction of blast geometries and preservation of the integrity of the in-situ rock mass. Lesser environmental impacts in the form of less ground vibration, lesser fly rocks, less air overpressure generation. It has also found acceptance in underground tunnelling, with outstanding improvements in terms of advance and overbreak control and has been delivering unique ore recovery and productivity benefits in mass mining. The digital detonator offers an effective and smart tool for flexible initiation sequences to provide new and creative solutions to the mining and construction industry which was never possible before.

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