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DETONATOR: EVOLUTION, CLASSIFICATION AND COMPARISON

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Abstract

Parallel to the evolution of explosives, initiation devices have gone through important technological advances since the decade of the forties in an attempt to obtain the following objectives:

- Energetic initiation of the more modern explosives, which are much more insensitive than the classical dynamites but also safer.
- Control over initiation times to improve fragmentation.
- Reduction of the vibration levels, air blast and flyrock produced in blasts.
- Punctual priming, either at the top or base of the blasthole, or axial priming.
- More speed and flexibility in breakage operations while maintaining a high degree of safety for personnel and installations.

At present, the firing systems for the detonators called ordinary blasting caps by means of a safety fuse, which implies high risk for the blaster and a lack of control over ignition timing with negative effects on the blasting yields and the alterations that could occur, has almost completely been substituted by safer and more trustworthy systems that can be classified in two groups:

- Electric systems, and
- Non-electric systems

1. Introduction

Blasting is usually the first step in any mining process and its result influence the efficiency of process to varying degrees. Initiator is a term that is used in the explosive industry to describe any device that may be used to start a detonation in explosive. Detonation is the process 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 in a stable manner. The devices that initiate high explosive are called detonators. All types of explosive cannot be readily initiated by the application of heat by burning. In order to initiate explosives, a powerful detonation is required. Initiating devices does this. Detonators are compact devices that are designed to safely initiate and control the performance of larger explosive charges. They contain relatively sensitive high explosives which can be initiated by electrical or shock energy from an external source. The strength of detonators is determined by amount of base charge contained and identified by strength number.(Jimeno 1995)

2. Importance of initiation system in blasting

Authors Blasting is usually the first step in any mining process and its result influence the efficiency of process to varying degrees. Blast results are considered good when they ensure good digging and loading operation while maintaining the safety and environment standards. Initiator is a term that is used in the explosive industry to describe any device that may be used to start a detonation in explosive. Detonation is the process 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 in a stable manner. The devices that initiate high explosive are called detonators and devices that start burning or deflagration are called squibs. (Konya 1991) It is assumed that the holes have been laid out and drilled in the designed pattern and the objective of initiators is to communicate with the holes so that it may ensure:

- The sequence in which the holes (or portion of the holes) should fire,
- The time delay between holes, rows or decks and,
- The energy required to begin the detonation process.

It has been emphasized that precisely controlled release of explosive energy in a sequence of blast holes yield better fragmentation. Hence, accuracy is necessary over the blast detonation sequence to bring direct impact on over all blast performance. Any variation in hole detonation timing result in that hole being fired prior to or after its nominal firing time due to which holes could potentially detonate can have adverse impact on the performance of a blast. The result of these impact have briefed as following:

- Poor rock fragmentation
- Large amount of oversize
- High ground vibration levels
- High air blast levels
- Fly rock incidents
- High downstream process costs

2.1 Chronology of development of initiating devices

1830	Moses Shaw patented a way of electric firing black powder(gunpowder) by an electric spark
1831	William Bickford introduced safety fuse which consists of a core black powder enclosed in textile sheaths and suitably waterproofed
1830-32	Robert hare developed the bridge wire method of electrical blasting
1864-67	Alfred Nobel developed a method of initiating nitroglycerine by using safety fuse for initiating black powder detonators and later capsules of mercury fulminate. Those become the first commercial detonators.
1870	Julius Smith successfully introduced bridge wire initiated electric blasting caps and developed a portable, generator type blasting machine.
1895	Julius Smith introduced delay electrical blasting caps utilizing safety fuse as the delay train.
1907	First detonating cord ‘Cordean’ invented by Louis L’heaur in France using TNT core.

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1930	Replacement of mercury fulminate in initiation and primer charges was begun with the use of variety of more stable explosive compound.
1937	Detonating cord with PETN
1946	Millisecond interval delay blasting caps introduced, having delay intervals in millisecond rather than seconds.
1948	Use of capacitor discharge type blasting machines began replacing the generator types with safe and more reliable power units.
1950	Development of delay connection.
1960	Low energy detonating cord introduced which led to improved non-electric detonating systems.
1966	Work on NONEL started by Nitro Nobel. The first successful trials were in the laboratory in 1968.
1973	Non-electric delay detonators NONEL introduced which provided improved timing and reduces noise levels. The first factory to produce NONEL was commissioned in Gyttorp, Sweden.
1981	Magnet system introduced.
1984	Laser profiling development by Huddleston and Buzuns
1986	Electronic detonators introduces by ICI(UK) (Dekovic 2003)

2.2 Types of Detonator

2.2.1 Safety fuse and Plain detonators

Initiation of plain detonator is by means of safety fuse. It is mainly used to fire multiple holes blasts. These detonators comprises of aluminum tube filled with two charges:

- A base charge of high velocity explosive (PETN) in the bottom of the tube.
- A primer of lead azide composition.

The burning from the safety fuse converts the primer charge into detonation, and initiates the explosive base charge.

The aluminum tube is 6 mm in diameter and 37-50 mm long. Standard detonator of strength 6 is popularly used. It burns at a rate of 120 seconds per meter.

It was the substitution of expensive fulminate with a primary (initiating) charge and a base charge of high explosive. It consists of Primary charge of ASA and base charge of PETN or RDX.

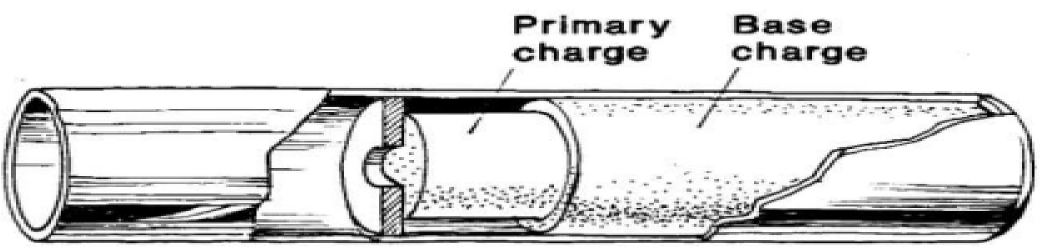

Fig 2.1 Plain detonator cross section

2.2.2 Electric detonators

The electric detonator consists of a cylindrical aluminum or copper shell containing a series of powder charges. Electrical energy is introduced into the detonator from the exploder (battery, hand-driven magneto or charged capacitor) via a primary circuit wire (shotfiring cable) and detonator leads and is supplied to the cap by means of two leg wires that are internally connected by a small length of high-resistance wire known as the bridge wire. The bridge wire serves a function similar to the filament in an electric light bulb. When a current of sufficient intensity is passed through the bridge wire, the wire heats to incandescence and ignites a heat-sensitive flash compound. Once ignition occurs, it sets off a primer charge and base charge in the detonator either instantaneously or after traveling through a delay element that acts as an internal fuse.
This delay element provides a time delay before the base charge fires. The leg wires are made of either iron or copper. Electric detonators are of two types.

2.2.2.1 Instantaneous Electric Detonator

In this type of detonator an electro-explosive device called "fuse head" or a 'match head" provides initiation. The primer charge and base charge are same as of plain detonator, Instead of using safety fuse to initiates, electric current is passed through a fuse- head having resistance wires. This type of detonator is used in small size blasts such as rock breaking in quarries and in accurate contour hole blasting.

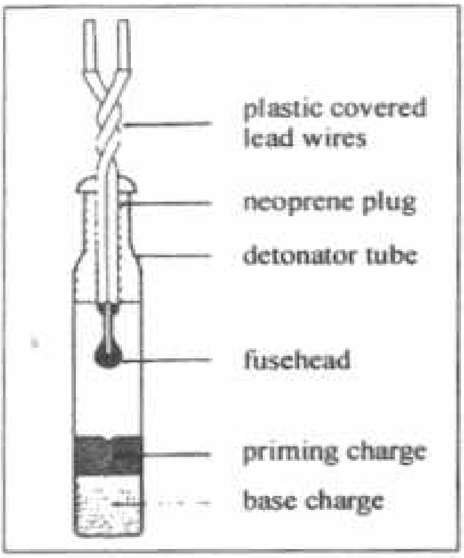

Fig 2.2 Instantaneous Electric Detonator

2.2.2.2 Delay Electric Detonator

Delay Blasting
Generation of blasts induced ground vibration is related to the amount of explosive detonation at any one time. By using millisecond delays the amount of explosives fired at one given instant may be reduced by different delay period for different holes. This helps in moving more explosives in bigger blasts having more blast holes. Fragmentation resulting from a blast is also influenced by the time interval provided by the millisecond delay detonator. Each holes having separate millisecond delay timing, provide free faces for the better throw of the holes so as to result desired fragmentation level.
Selection of delay interval varies with the type of rock and burden distances. However, it is experienced that the optimum delay interval lies between 3 and 6 ms/m burden.

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Delay Electric Detonator

- Same as instantaneous electric detonator, except for inclusion of delay powder.
- Delay time based on length and composition of delay powder.

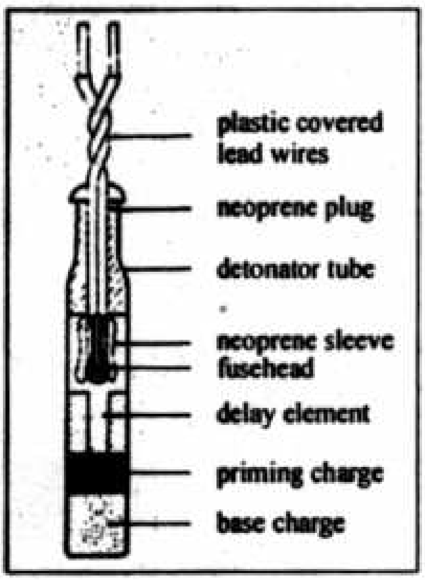

Fig 2.3 Delay Electric Detonator

Selection of circuit, principle of successful blasting and risk associated with electrical detonator.

The simplest and most convenient way to connect electric detonators is in series. If one or more detonator connections are faulty then the entire circuit will not fire, eliminating the possibility of having explosive in the broken rock after firing. Connection in series allows the entire circuit to be tested for continuity and resistance from a safe place. In a parallel circuit, in which each detonator is connected across two common wires, each detonator is independent of the others. The circuit resistance is lower but even if one connection of faulty the remainder will fire, resulting in unexploded charges in the muck pile. Each individual detonator must be tested for continuity.

It also depends upon the number of detonators to be fired and the type of operation. A simple series circuit is used on small blasts, consisting of less than 50 detonators. A series-in-parallel circuit is used when large number of detonators is involved.

Successful electrical blasting depends upon four general principles:

- Proper selection and layout of the blasting circuit.
- Adequate energy source compatible with the type of blasting circuit selected.
- Recognition and elimination of all electrical hazards, and
- Circuit balancing, good electrical connections and careful circuit testing.

Electric blasting initiators of the usual types function very effectively and without undue hazard when they are used in locations free from sources of electricity extraneous to that intentionally provided in the blasting circuit. When, however, extraneous sources of electricity are present, there is the danger that the usual blasting initiators may fire prematurely. Various types of extraneous electricity are frequently un-avoidably present in locations where blasting caps are intended for use. Such sources may be mentioned as lightning, atmospheric static electricity, such as, is generated by dust storms, snow storms, escaping steam, moving belts, revolving automobile tires, or such as is likely to be present at high altitudes and especially in regions of low humidity. Another source of unwanted electricity exists in stray currents, that is, differences in potential that exist in highly metallic rock formations, as in ore mines, for example, or in the vicinity of electric cables, rails, pipelines, and ventilating ducts. There is also the possibility that instances of galvanic action may occur in the vicinity of electric blasting initiators which may cause a sufficient difference in potential to fire electric initiators.(Bhandari 1997)

2.2.3 Non Electric detonators

Non-electric initiation systems have been used in the explosive industry for many years. Cap and Fuse was the first method of non-electric initiation. Typical non-electric system used today consists of detonating cord, shock-tube detonators or a combination of the two.

Non-electric initiation systems have safety advantages of immunity to stray electric current and radio frequencies. However, these systems are susceptible to accidental initiation by a lightning strike. Non-electric detonators contain sensitive ignition charges and base charges and can be accidentally detonated by heat or impact.

Non-electric systems require an orderly hookup, and careful visual inspection is necessary to verify the continuity of the system.

2.2.3.1 Detonating Cord

Detonating cord is a round, flexible cord containing a center core of high explosive, usually (pentaerythritol tetranitrate) PETN at a content of 3.6 to 7.0 g/m. The exterior sheathing is waterproof material surrounded by a reinforcing textile and plastic wrapper. Detonating cord acts as a carrier of detonating wave which is used to detonate the primer. The velocity of detonation (VOD) is around 7000 m/s. Detonating Cord is usually initiated by means of an electric detonator.

Detonating cord is insensitive to ordinary shock and friction. Surface as well as inhole delays, can be achieved by proper delay devices attached to detonating cord. For examples: millisecond connectors (MSCs). MSCs consist of two plastic blocks, each containing an identical delay detonator, linked by a short length of signal tube.

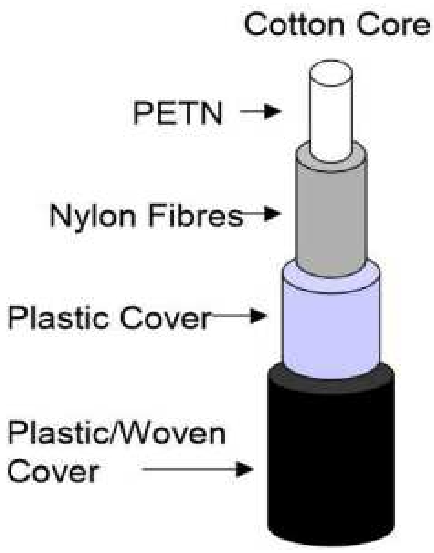

Fig2.4 Detonating Cord Make

2.2.3.2 Shock Tube Initiation System

The shock tube is a non-electric, instantaneous, non-disruptive signal transmission system. The system detonates in a plastic tube that has a thin coating of reactive material on the inside. This reactive material has a powder weight of about 0.1 grains per foot (1/70,000 pounds), approx one teaspoon per km of tube and propagates a noiseless shock wave signal at a speed of approximately 2000 m/s. The system eliminates all electrical hazards except possible initiation by direct lighting strike. Shock tube systems take a precise energy input to initiate the reaction inside the tube. It may be initiated by detonating cord, electric blasting cap, cap and fuse or a starter consisting of a shotgun primer in a firing device.(Podoliak 2004) The unique aspects of shock tube systems are:

- It is not susceptible to stray electric currents.
- Separate lengths of signal tube cannot initiate each other through direct contact, knots or other simple connections.
- The tube is robust, having a high tensile strength and abrasion resistance.
- It is very difficult to ‘kink’.
- The initiation is virtually non-violent compared to detonating cord and is hence much safer to use.

2.2.3.2.1 NONEL

Nonel is a shock tube detonator designed to initiate explosions, by shock wave which travels through the tube. Instead of electric wires, a hollow plastic tube delivers the firing impulse to the detonator, making it immune to most of the hazards associated with stray electrical current. It consists of a small diameter, three-layer plastic tube (outer dia=3mm and inner dia=1.2 mm) coated on the innermost wall with a reactive explosive compound, which, when ignited, propagates a low energy signal, similar to a dust explosion. The reaction travels at approximately 2,000 m/s along the length of the tubing with minimal disturbance outside of the tube. The entire reaction takes within the tube, which remains intact throughout the process. Because of this:

- The tube by itself is not classified as an explosive.
- It does not affect anything around it. When used as a down line, it does not effect the surrounding explosive.
- The reaction is quite silent. This has environment advantage over detonating cord.

Nonel was invented by the Swedish company Nitro Nobel in the 1960s and 1970s and was launched to the market in 1973. Eco friendly and productive blasting operation can be achieved using these systems when implemented judiciously. Blasting can also be done in sensitive regions with greater ease and confidence.

Fig2.5 NONEL Detonator Cross Section

2.2.4 Electronic detonators

Electronic detonator systems are new technology advancements for the initiation of blasts in mining operations. Their introduction for use in mine blasting operations continues to advance. Several advantages for using electronic detonators are precise timing, reduced vibrations, a reduced sensitivity to stray electrical

currents and radio frequencies, and a great reduction in misfires through more precise circuit testing. The detonators can be programmed accurately with a delay between 0 ms to 800 ms with an interval of 1ms.
Electronic detonators have been designed to eliminate the pyrotechnic fuse train that is a component of electric detonators, thus improving timing accuracy and safety. For the electronic detonators, typically an integrated circuit and a capacitor system internal to each detonator separate the leg wires from the base charge. Depending on the design features of the electronic detonator, the safety and timing accuracy can be greatly improved. The electronic detonator is obviously a more complex design compared to a conventional electric detonator.
A specially designed blast controller unique to each manufactured system transmits a selectable digital signal to each wired electronic detonator. The signal is identified by each electronic detonator and the detonation firing sequence is accurately assigned. The manufacturer's control unit will show any incomplete circuits during hook up prior to initiation of the explosive round. The wired round won't fire until all detonators in the circuit are properly accounted for with respect to the current blasting plan layout.

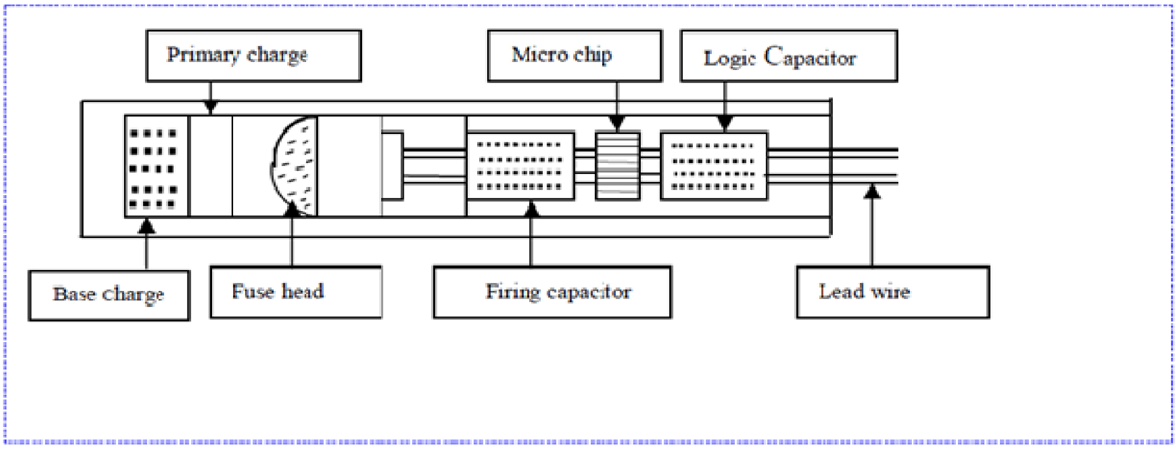

Figure 2.6: Electronic detonator

3. Conclusion

Detonator types is being studied and following conclusion is made.

Non-electric system

- Higher safety of blast work, as the system is immune to initiation by foreign sources of electric energy (radio frequency, stray currents).
- Higher variability of timing patterns enabling "tailor-made" blasts corresponding to the Conditions in a given locality.
- More effective work from the point of view of logistics and storage (smaller product range necessary for achieving a given result) and Fit for use in wet conditions and under water
- High variability of timing, Reduction of vibration during blast and Better fragmentation
- The most critical point in the excavation working cycle is network building of the blast holes, Use of electric initiators requires expert coordination of the blasting crew because of connection of electric conductors. Network building by non-electric system is quicker and simpler, and the possibility to leave out certain charges is smaller.

All the mentioned benefits improve economy of blasting operations. Although the initial cost of using non-electric system may be higher, the overall economics of blasting and quarrying operations is more beneficial as opposed to traditional electric system.

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- Non-electric detonators must not be used in worksites with coal dust and methane atmosphere
- Practical problem of this type of detonator is the impossibility of checking the firing circuits, as only visual inspection can be carried out.

Electric initiating system

Electric blasting initiators of the usual types function very effectively and without undue hazard when they are used in locations free from sources of electricity extraneous to that intentionally provided in the blasting circuit. When, however extraneous sources of electricity are present, there is the danger that the usual blasting initiators may fire prematurely. Various types of extraneous electricity are frequently unavoidably present in locations where blasting caps are intended for use. Such sources may be mentioned as lightning, atmospheric static electricity such as is generated by dust storms, snow storms, escaping steam, moving belts, revolving automobile tires, or such as is likely to be present at high altitudes and especially in regions of low humidity. Another source of unwanted electricity exists in stray currents, that is, differences in potential that exist in highly metallic rock formations, as in ore mines, or in the vicinity of electric cables, rails, pipelines, and ventilating ducts, and the like, long conductors of some or all of these types being customary in mines. There is also the possibility that in stances of galvanic action may occur in the vicinity of electric blasting initiators which may cause a sufficient difference in potential to fire initiators.

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