Use of electronic initiation systems in mining industry

Uporaba elektronskih inicialnih sistemov v rudarstvu

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Abstract: The use of explosives for minerals extraction has always been a highly contentious area. The associated environmental impact is frequently an issue that curtails the sustainable development of many quarrying operations. However blasting is quite often the only economic means of mineral extraction. It is therefore vital for the industry to do all that it can to reduce the vibration levels experienced at adjacent properties due to quarry blasting without imperilling the financial viability of the enterprise. Over the past twenty years we haven't seen any major development in initiation technology, with the last major development being the release of the Nonel detonation system in 1973. By more accurately controlling timing delays, electronic initiation detonator systems can increase rock fragmentation, lower vibration levels, reduce oversize; lessen the potential fly-rock. This translates into faster excavation times and improves downstream processing costs for the mining operation by increasing throughput, reducing crusher wear and lowering power consumption and maintenance costs. The purpose of this paper was to examine the use of Electronic Detonators and their relevance in to the Slovenian mining industry.

Povzetek: Uporaba minsko razstrelilnih sredstev pri pridobivanju mineralnih surovin je imela vedno poseben dvorezen pomen/vlogo. S tem povezan negativni vpliv na okolje je bil zato pogosto predmet zmanjševanja njihove uporabe v rudarskih pridobivalnih de-

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lih v smislu trajnostnega razvoja. Kakor koli že, uporaba metode razstreljevanja omogoča velike ekonomske učinke pri pridobivanju mineralnih surovin in je zato zelo zaželena. Prav tako ima poseben pomen tudi za preostalo industrijo, še posebej zaradi možnosti zmanjševanja današnjih seizmičnih vplivov pri miniranjih v kamnolomih brez posebnih finančnih učinkov na poslovanje. V preteklih dvajsetih letih ni bil opazen znaten napredek na področju inicialnih tehnologij, kjer je bil zadnji večji razvoj zaznan z odkritjem neelektričnega inicialnega sistema Nonel leta 1973. Z bolj natančnim nadzorom časa zakasnitve detonacije lahko z uporabo elektronskih inicialnih sistemov dosežemo izboljšanje fragmentacije/granulacije materiala po razstreljevanju, nižji nivo seizmičnih valov, zmanjšanje prevelikih kosov in zmanjšanje potencialne nevarnosti razmeta materiala. To posledično omogoča učinkovitejši čas pridobivanja in s tem zniževanje stroškov pridobivanja, drobljenja in mletja zaradi manjše obrabe strojih delov, porabe energije in vzdrževanja. Namen članka je predstaviti elektronske detonatorje in pomen uporabe za slovensko rudarsko industrijo.

Key words: electronic detonator, electronic initiation system
Ključne besede: elektronski detonator, elektronski inicialni sistem

INTRODUCTION

The mining and explosive industries rapidly embracing new technologies, in order to improve overall performance, efficiency and cost-effectiveness in various types of blasting and also to mitigate its adverse effects. Most recently, technology that is developed to improve techno-economics and reduction of most of adverse effects in usage of explosive and blasting is »Precise and Accurate Delay Timing - Digital or Electronic Detonator« system.[3]

Broadly speaking, accurate and flexible timing allows blasters to make small hole-to-hole and row-to-row changes to account for drilling inaccuracies. Adjusting the blast design to actual conditions can improve safety and fragmentation, which can cut costs by optimizing the loading and hauling cycle, increasing crusher throughput, and reducing the amount of oversize handling and secondary breaking. In addition, precise and variable delay timing manipulations have enhanced highwall stability and bench crest preservation, resulting in safer mines operations and also for reduction of blast induced ground vibration. These improvements allow for more accurate placement of boreholes for succeeding blasts. Thus, the precision in delay timing has advantages such as:

- Better ground vibration control,
- Better control of rock movement and muck profile,
- Better fragmentation,
- Enhancement in productivity by optimizing utilization of explosive energy.

Mining activities remain a time and cost-intensive business therefore, accurate planning, cost efficiency have been the important factor in excavation operations. In a move to improve overall cost-efficiency in large mining and construction operations operator are adopting the use of Electronic Detonation blasting technology. The accuracy and flexibility of the programmable detonator have provided the mining industry with options, previously not available to improve timing designs for increased benefit in the areas of ground control and better fragmentation. The industry's whole approach to blast timing design can now be focused on greater safety, increased productivity and blast performance, rather than being restricted by the limited interval selections and inaccuracies the conventional pyrotechnics timing systems offer. The growing popularity of high-accuracy electronic detonators means the potential for an expansion of a quarry blasting program's capabilities and improved safety as well.

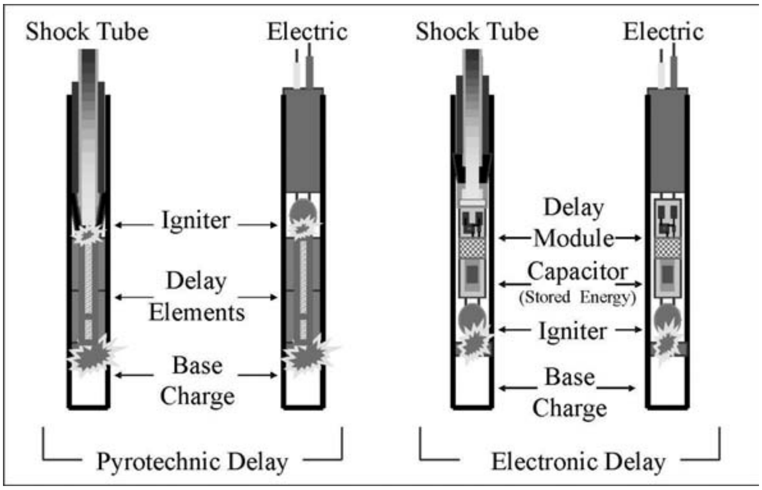

Figure 1. Pyrotechnic and Electronic delay initiation system[9]

Understanding electronic delay initiation system

In order to understand the Electronic delay initiation system, we compare Pyrotechnic system and Electronic delay initiation system. There are several types of electronic systems being tested and used in the mining industry, all of which utilize some type of stored energy device to provide energy for their timing and firing circuits. All Electronic Detonators has a system to store electrical energy inside the detonator as a means of providing delay timing and initiation energy.

Fundamental Construction Differences[3]:

- Basic differences in Electronic Delay with Pyrotechnic system of delay is in location of Ignitor/Fuse head,
- In Electronic Detonator Ignitor/Fuse head is located below delay (timing) module,
- In Pyrotechnic system (Shock Tube and Electronic Detonator) Ignitor/Fuse head is located ahead of Delay elements.

One of the basic differences in electronic delay with pyrotechnic system of delay lies in the location of Igniter. In electronic detonator the Igniter is located below the delay (timing) module, whereas both shock tube and electric detonator (Figure 1) utilizes the igniter ahead of delay element (shock tube function as igniter in the shock tube device). Other basic difference in design of electronic detonator is the use of some type of stored electrical energy device, typically capacitor, is used

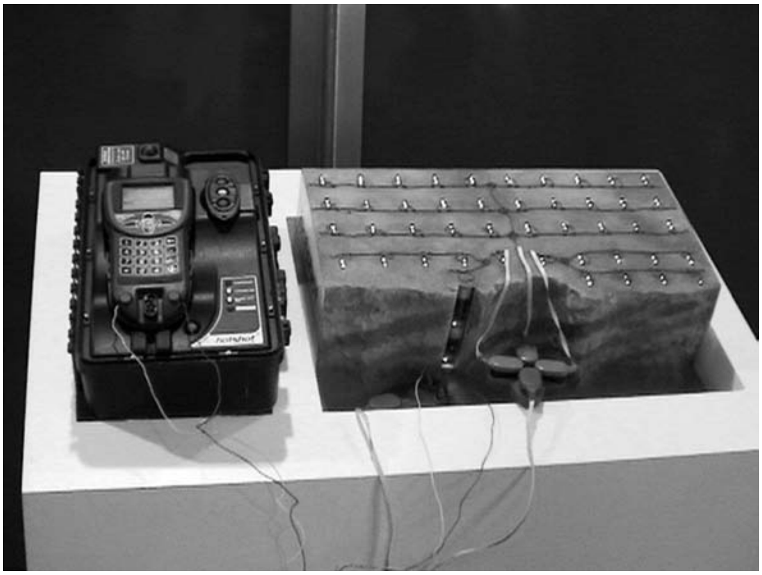

Figure 2. Electronic blasting system (DynoNobel HotShot)

in the delay module. The construction and design of electronic detonator varies from manufacturer to manufacturer.

In case of electronic detonator which utilizes standard shock tube lead as the input signal, it transforms into electrical pulse through the use of a small explosive charge (booster) coupled to a highly efficient piezo ceramic element (generator) and (electrical energy storage cell (capacitor). Upon receipt of a thermal signal from shock tube the small explosive charge in the booster detonator fires. This activates the piezo ceramic device, which in turn causes current to flow through the steering diode to charge storage capacitor. A voltage regulator provides a sustantially constant voltage source to oscillator to control the frequency (Example of this kind of system is DIGIDET™ or Ensign-Bickford, USA)

The Programmable electronic detonator (Figure 3) utilizes standard lead as the input signal, which is transformed into electrical pulse through the use of principal component. Upon receipt of an electric signal causes current to flow through the steering diode to charge storage capacitor. A voltage regulator provides a substantially constant voltage source to oscillator to control the frequency. A "power on reset" circuit preloads the counter upon the initial application of the input voltage. Once the voltage on the storage capacitor has increased beyond a threshold setting the counter begin decrementing upon each input pulse from oscillator. As the counter digitally decrement past zero, the output to the firing switch activate and all remaining energy in the storage capacitor flows to the igniter. The end result is an electronic delay detonator.

Electronic detonator

There are several types of electronics systems, all of which utilize some type of stored electrical energy device (e.g. capacitor) to provide energy for their firing or timing/firing circuits. Their differences include detonator construction, timing precision, communication protocol, blasting machines, tie-in, connectors, etc. Although they are each uniquely different from one another, there are certain design features that are common to all. It is essential that users become fully educated on the products, procedures and recommended practices prior to use.

Electronic detonator systems are grouped into two basic categories:

- Factory Programmed Systems (fixed delay) and
- Field Programmed Systems (variable delay).

Factory Programmed Systems, in most cases, have a close resemblance to the conventional hardware and components found with standard electric detonators. In some cases, the user may even have a difficult time differentiating a wired electronic detonator from a wired electric detonator. Even though these units may not appear to be different, electronic detonators generally cannot be fired or shot using conventional blasting machines or firing devices. Each system can have a unique firing code or communication protocol used to fire the detonators in the blast.

Factory Programmed Systems can be further grouped into specific types or styles. There are Electrically Wired Systems, where each manufacturer has a specific wiring style or methodology; and Factory Programmed Systems that utilize shock tube technology to energize an electronic timing circuit within the detonator.

Factory Programmed Systems

Factory Programmed Systems utilize "fixed" delay periods for the blast design. Holes are generally loaded and hooked up in the same manner as standard electric or shock tube systems. Depending on the manufacturer, some type of surface connector may be utilized for ease of wiring, or maintenance of correct electrical polarity. With some systems, correct polarity must be observed when electronic detonators are attached to the firing circuit, otherwise a misfire may occur. In all cases though, users of these systems should always consult the manufacturer for specific application information and instructions.

Field Programmed Systems

Field Programmed Systems utilize electronic technology to program delay times at the blast site. Each system is manufactured for, or with, unique system architectures, styles, hardware and communication protocol. There are no fixed delay times associated with these detonators. These systems rely on direct communication with the detonator (either prior to loading, after loading, or just prior to firing) for the proper delay time and subsequent blast design. 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.

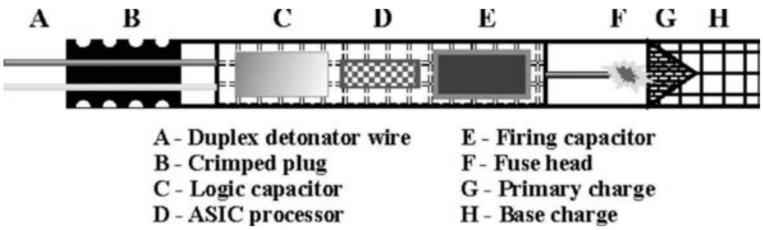

Figure 3. Cross section of Programmable Electronic Detonator

Significance of accuracy of delay timing

The pyrotechnic detonator design is such that the average scatter of delayed firing is ±10 %. This implies that for a blast-hole that should fire at 25 ms from initiation, might fire at 22.5 ms or 27.5 ms. This may not seem like a huge variance, but the resultant effect is. The scatter on a 500 ms delay detonator will cause it to fire anytime from 450 ms to 550 ms i.e. a range of 100 ms. If taken into account that inter-hole delays of 10 ms are used on a blast, out of sequence hole firing is almost guaranteed.

In general, accurate and flexible timing allows blasters to make small hole-to-hole and row-to-row changes to account for drilling inaccuracies. Adjusting the blast design to actual conditions can improve safety and fragmentation, which can cut costs by optimizing the loading and hauling cycle, increasing crusher throughout and reducing the amount of oversize handling and secondary breaking. In addition, precise and variable delay timing manipulations enhances high-wall stability and bench crest preservation resulting in safer mines operations and also for reduction of blast induced ground vibration. These improvements allow for more accurate placement of boreholes for succeeding blasts. Optimization of the blast design to take greater advantage of the electronic detonator's precision expands the blast pattern and reduces the explosive consumption without negatively affecting production. Electronic detonators generally are programmable in 1ms increments and have delay accuracy (scattering) as small as ±0.5 ms.

The control of blast vibrations is an increasingly important factor within the rock blasting industry. Much research work has looked at optimising the inter-hole delay period to minimize vibration. The most commonly used technique utilising inter-hole delays is Linear Superposition. This is a method whereby a vibration signal from a single-hole shot is combined with the firing times to simulate the vibration signal generated by a full-scale production blast. The simulation can be run many times with varying delay times to find the optimum value which will produce the minimum vibration level. Reamer et al. [10] give a very good description of this technique.

The successful implementation of Linear Superposition relies on two very important assumptions:

- The firing time of each hole can be accurately controlled.
- The single-hole vibration signal is a good representation of the vibration produced by each hole in a production blast.

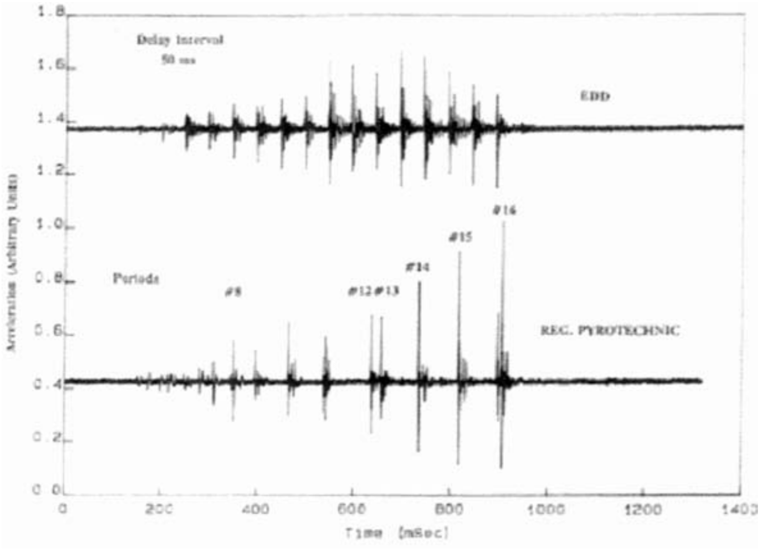

Figure 4. Comparison of firing times between electronic delays (ED) an the regular pyrotechnic delays (SP) for the same 50 ms delay interval in quarry blasts (three holes/delay in an echelon design)[6]

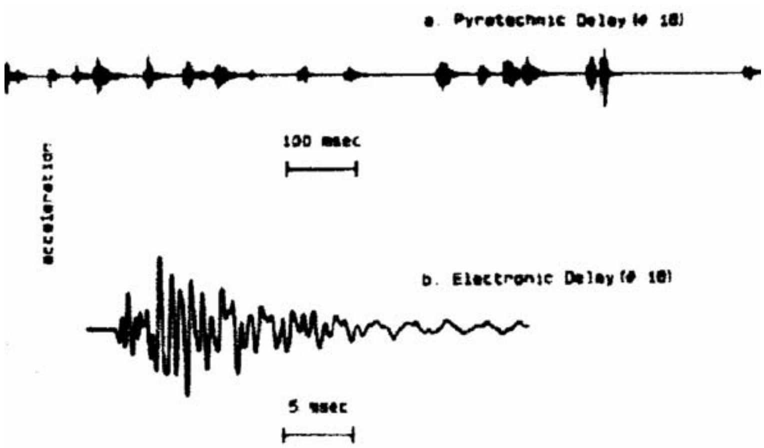

Figure 5. Comparison of hole firing times for regular pyrotechnic and electronic delay for the sixteen perimeter holes connected to the same delay[6]

Initiation timing can now be accurately controlled with the advent of electronically delayed detonators and accurately determined by using very high speed solid state data loggers to record "Velocity of Detonation" (VOD) information.

The assumption that the single-hole test shot provides a vibration signal that is representative of all the holes in a production shot is more problematic.

Yuill & Farnfield[7] found that, whilst vibration signals from a series of single-hole shots are consistent in shape despite variations in the hole design and explosive type, the amplitude of the vibrations was variable. They went on to state that the instantaneous charge weight; free faces and burden controlled the amplitude of these vibrations.

Whittaker, Chiappetta & Stump[8] found that in the near field, vibration amplitudes and dominant frequencies were significantly affected by using decked charges over full column charges, for a given explosive. They also showed that the results are very site specific and only apply to the near field, once a critical distance is exceeded no significant differences are found regarding the dominant frequencies or vibration amplitudes.

Birch & Hosein[2] indicated that different holes in any given small blast perform a slightly different function that will inevitably have an effect in the final vibration signal produced. They also demonstrated it was possible to deconstruct the blast signals in such a way as to show that the timing times did have an effect on the wave shape of the vibration and that the different timings did produce differing amplitudes of vibration.

To provide comparison between the different blasts a measurement termed the 'Scaled Distance – SD' was used. This is a value which represents the distance of the seismograph from the centre of the blast while taking into account the maximum instantaneous charge detonated therefore providing a comparable situation. The formula used for the calculation of scaled distance was taken as is shown below as it is the standard used in many publications.[1]

$$SD = \frac{D}{MIC^a} \quad (1)$$

$$PPV = H \cdot (SD)^b \quad (2)$$

where;
SD – scaled distance (m/kg^a)
D – distance to the centre of the blast (m)
MIC – maximum instantaneous charge (kg)
a – charge weight exponent
PPV – peak particle velocities (mm/s)
H – particle velocity intercept.
b – slope factor exponent

The empirically determined values in equations for *H*, *a*, and *b* for each of the three components of motion longitudinal, vertical, and transverse. Charge weight and distance are the principal factors that affect vibrations and are subject to control. The values of *a*, *b* and *H* are dependent on rock type, rock density, rock bedding, slope of beds, thickness of over burden, nature of terrain, blasthole conditions, presence or absence of water.[11] They also affect the transmission of vibrations, but are beyond control. The values of $a = 0.5$ and $b = -1.6$ are generally accepted as workable first approximations until applicable data indicate a change. The value of $H = 438$, however, is highly variable and is influenced by varying factors.

Figure 6. illustrates five resultant traces (two Non-electric and three Electronic) recorded at the same monitoring location. The peak resultant values for the non-electric traces appear close to the begining of the signal traces with the levels reached being unmatched through out the rest of the traces. In comparison the peak resultant values for the electronic traces are more randomly distributed throughout the entire duration of their signal traces. All the peaks throughout the electronic traces appear to be more regularly distributed than the non-electric with the actual peak values appearing to be only slightly higher than what could be considered to be the average peak values for a given blast.[4]

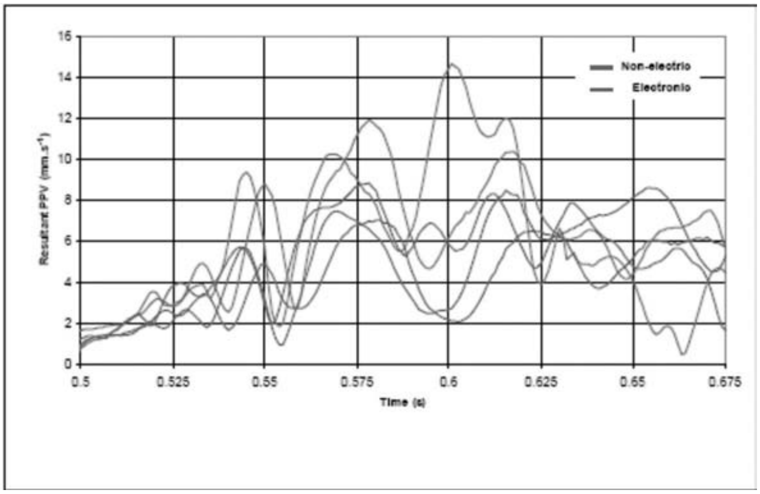

Figure 6. Comparison of hole firing times for two Non-electric and three Electronic traces (PPV - peak particle velocities measured in millimetres per second)[4]

Conclusions and plans for future work

The indication from the literature is that Electronic Initiation Systems will offer benefits in ground vibration control, fragmentation control, muck pile contours, reduction in fly rock incidents, increase possible round sizes and presents an opportunities to develop new blasting methods. Of course with all new technology the benefits are offset to some extent by the drawbacks and electronic initiation is no exception.

Electronic initiations have problems in that they can be very complex systems, which require lengthy training and are much more expensive than Nonel Detonators, also the complexity of the systems increases the possible sources of risk of malfunction. As most of these systems are still being developed and proven there is still room to address these issues, the first two are economic which is a site-specific decision where as the third is an issue of safety. Safety is not site specific and should be inherent in any new technology that it has a higher level of safety than the superseded technology.

The conclusion was that technically and operationally the electronic systems seem vary proficient and from the results of the various tests and case studies that have been carried out they have a great deal of benefit to offer the Slovenian mining industry.

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