GENERAL ATF REGULATIONS CONCERNING EXPLOSIVES

(Revised September, 2005)

Please read the following information:

It is Cal/OSHA's policy not to require Federal ATF Clearance, Permits or Licenses before testing for a California Blaster's License.

However, this policy does not exempt California Blasters from Federal ATF regulations which are briefly outlined as follows:

a. If you are a manufacturer, importer, or distributor of explosives, you must have an ATF *License* to perform these activities.

b. If you are a company or self-employed blaster who purchases, transports or uses explosives, you must have an ATF *Permit*. Also, the Responsible Persons must be identified, and submit their fingerprints and photographs to ATF for a background check.

   An unemployed blaster must also have an ATF permit to purchase, transport, or use explosives.

c. If you are an employee of a company holding an ATF License or Permit, and you will possess explosives, actually or constructively, your employer, if they have been given a 3-year license by ATF after June 1, 2003, will have to submit your name and information about you to ATF within 30 days for a background check, as an "employee possessor" or EP. Constructive possession includes drivers, magazine keepers, and others who may come in actual contact or have access to explosive materials.

   Whether or not a background check has been conducted, all ATF explosive licensees and permitees (and employers) must not knowingly allow any prohibited person to purchase, transport or use explosives.

   Prohibited Persons usually include:
   1.) A person under indictment for or convicted of a felony
   2.) A fugitive from justice
   3.) An unlawful user of or an addict to a controlled substance (drug user)
   4.) An adjudicated mental defective
   5.) An alien (with certain exceptions)
   6.) A person who has been dishonorably discharged from the Armed Forces
   7.) A person who has renounced U.S. Citizenship

d. If you have any questions regarding these Federal Policies, you may call ATF at 202-927-2310, or go online to: www.atf.gov

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BACK TO BASICS: INITIATION AND PRIMING

by
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The initial energy source may be electrical, such as a generator or condenser-discharge blasting machine or a powerline used to energize an electric blasting cap, or a heat source such as a spark generator or a match. The energy conveyed to and into the individual blastholes may be electricity, a burning fuse, a high-energy explosive detonation, or a low-energy dust or gas detonation.

INITIATION SYSTEMS

A considerable amount of energy is required to initiate a high explosive such as a dynamite or cap-sensitive slurry. In blasting, high explosives are initiated by a detonator, which is a capsule containing a series of relatively sensitive explosives that can be readily initiated by an outside energy source. Blasting agents, which are the most common products used as the main column charge in the blasthole, are even less sensitive to initiation than high explosives. To assure dependable initiation of these products, the initiator is usually placed into a container of high explosives, which in turn is placed into the column of blasting agent.

An initiation system consists of three basic parts.

- An initial energy source.
- An energy distribution network that conveys energy into the individual blastholes.
- An in-the-hole component that uses energy from the distribution network to initiate a cap-sensitive explosive.

The initial energy source may be electrical, such as a generator or condenser-discharge blasting machine, or a powerline used to energize an electric blasting cap, or a heat source such as a spark generator or a match. The energy conveyed to and into the individual blastholes may be electricity, a burning fuse, a high-energy explosive detonation, or a low-energy dust or gas detonation. Figure 1 shows a typical detonator or "business end" of the initiation system. This detonator, when inserted into a cap-sensitive explosive and activated, will initiate the detonation of the explosive column. Commercial detonators vary in strength from No. 6 to No. 12. Although No. 6 and No. 8 detonators are the most common, there is a trend toward higher strength detonators, particularly when blasting with cap-sensitive products which are less sensitive than dynamites.

The primer is the unit of cap-sensitive explosive containing the detonator. Where the main blasthole charge is high explosive, the detonator may be inserted into the column at any point. However, most of the products used for blasting today (blasting agents) are insensitive to a No. 8 detonator. To detonate these products, the detonator must be inserted into a unit of cap-sensitive explosive, which in turn is inserted into the blasting agent column at the desired point of initiation.

The discussions of the various initiation and priming systems will concentrate primarily on common practice. With each system there are optional techniques and "tricks of the trade" that increase system versatility. It is a good idea to confer with the manufacturer before finalizing your initiation and priming program so you fully understand how to best use a specific system.

DELAY SERIES

Figure 1 shows an instantaneous detonator. In this type of detonator, the base charge detonates within a millisecond or two after the external energy enters the detonator. However, in most types of blasting, time intervals are required between the detonation of various blastholes or even between decks within a blasthole. To accomplish this, a delay element containing a burning powder is placed immediately before the priming charge in the detonator. Figure 2 shows a delay detonator.

There are three basic delay series: slow or tunnel delays, fast or millisecond delays, and coal mine delays for use in underground coal mines. For all commercial delay detonators, the delay time is determined by the length and burning rate of the delay powder column. As a result, slow delay caps may be quite long in dimension whereas lower period millisecond delays are shorter. Although the timing of delay detonators is sufficiently accurate for most blasting needs, these delays are not precise, as indicated by recent research. Recently, however, manufacturers' tolerances for some delay caps have been tightened. It is important to use the manufacturer's recommended current level to initiate electric blasting caps. Current levels above or below the

... extremely high currents can speed up delay firing times. Near the minimum firing current, delays can become extremely erratic.

Slow delays are useful underground under tight shooting conditions where it is essential that the burden on one hole moves before a subsequent hole fires. This situation may occur in tunnels, shafts, underground metal-nonmetal mines, and in trenching. Slow delays are available with all initiation systems except surface detonating cord and delay cast primers. Delay intervals are typically 0.5 to 1 sec.

Millisecond delays are the most commonly used delays and are useful wherever the tight conditions previously mentioned are not present. Millisecond delays provide improved fragmentation, controlled throw, and reduced ground vibration and airblast as compared with simultaneous firing. They are available ... detonators, delay intervals are 25 to 50 ms in the lower periods and are longer in the higher periods. In detonating cord delay connectors, the delay may be as short as 5 ms.

Coal mine delays are a special series of millisecond delays. Since only electric initiation systems are permissible in underground coal mines, coal mine delays are available only with electric initiators. Delay intervals are from 50 to 100 ms, with instantaneous caps being prohibited.

Coal mine delays are a special series of millisecond delays. Since only electric initiation systems are permissible in underground coal mines, coal mine delays are available only with electric initiators. Delay intervals are from 50 to 100 ms, with instantaneous caps being prohibited. Coal mine delay caps always utilize copper alloy shells and iron leg wires. Iron leg wires are also available optionally with ordinary electric detonators and are used primarily to facilitate magnetic removal of the wires from the muck pile, such as in trona and salt mines.

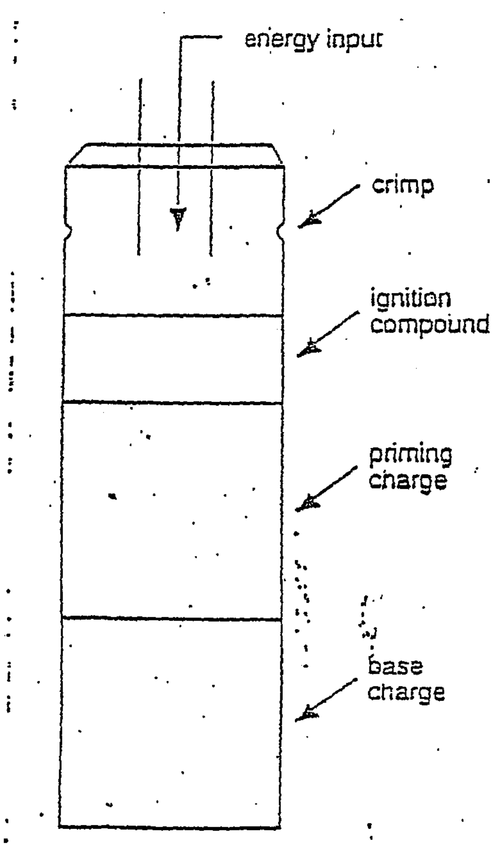

Figure 1. Instantaneous detonator.

ELECTRIC INITIATION

Electric initiation has been used for many years in both surface and underground blasting. An electric blasting cap consists of two insulated leg wires that pass through a waterproof seal and into a metal capsule containing a series of explosive powders (fig. 3). Leg wires of various lengths are available to accommodate various borehole depths. Inside the capsule the two leg wires are connected by a fine filament bridge wire embedded in a highly heat-sensitive ex- ... Upon application of electric current the bridge wire heats sufficiently to initiate the ignition mixture, which in turn initiates a series of less sensitive, more powerful explosives. Detonators are available in strengths ranging from about No. 6 to No. 12, with No. 6 and No. 8 being most common. Trends recently are toward higher strength detonators.

Most electric blasting caps have copper leg wires. Iron leg wires are available for use where magnetic separation is used to remove the leg wires at the preparation plant. Atlas Powder Co. has prepared an excellent handbook that describes electric blasting procedures in detail (1).

The Saf-T-Det and Magnadet electric blasting caps are two recent developments. The Saf-T-Det resembles a standard electric blasting cap but has no base charge. A length of 100-gr or less detonating cord is inserted into a well to act as a base charge just before the primer is made up. The device is similar to an electric blasting cap in regard to required firing currents and extraneous electricity hazards. The Saf-T-Det is manufactured in India and is not available in the United States at this time.

The Magnadet is also similar to a standard electric blasting cap, except that the end of each cap lead contains a plastic covered ferrite toroidal ring. The system is hooked up by passing a single wire through each ring. A special blasting machine is used to fire these detonators. The manufacturer, ICI of Scotland, claims ease of hookup and protection against extraneous electricity as advantages of this system.

TYPES OF CIRCUITS

In order to fire electric blasting caps, the caps must be connected into circuits and energized by a power source. There are three types of electric blasting circuits (fig. 4). In order of preference they are series, parallel series, and parallel.

In series circuits all the caps are connected consecutively so that the current from the power source has only one

Also, all the caps receive the same amount of current.

Figure 5 shows recommended wire splices for blasting circuits. To splice two small wires, the wires are looped and twisted together. To connect a small wire to a large wire, the small wire is wrapped around the large wire.

The electrical resistance of a series of caps is equal to the sum of the resistances of the individual caps. For most blasting machines, it is recommended that the number of caps in a single series be limited to 40 to 50, depending on the leg wire length. Longer leg wires require smaller series. The limit for most small twist-type blasting machines is 10 caps with 30-ft leg wires.

Many blasters minimize excess wire between holes to keep the blast site from being cluttered. The ends of the cap series are extended to a point of safety by connecting wire, which is usually 20 gage, but should be heavier where circuit resistance is a problem or when using parallel circuits. This connecting wire is considered expendable and should be used only once. The connecting wire is in turn connected to the firing line, which in turn is connected to the power source.

The firing line contains two single conducting wires of 12 gage or heavier, and is reused from shot to shot. It may be on a reel mechanism for portability, or may be installed along the wall of a tunnel in an underground operation. Installed firing lines should not be grounded, should be made of copper rather than aluminum, and should have a 15-ft lightning gap near the power source to guard against premature blasts. The firing line should be inspected frequently and replaced when necessary.

When the number of caps in a round exceeds 40 to 50, the parallel series circuit is recommended. In a parallel series circuit the caps are divided into a number of individual series. Each series should contain the same number of caps or the same resistance to assure even current distribution. The leg wires of the caps in each series are connected consecutively. Next, two bus wires, as shown in figure 4, are placed in such a position that each end of each series can be connected as shown in the figure. about 14 gage or heavier and may be either bare or insulated. Where bare wires are used, care must be exercised to prevent excessive current leakage to the ground. It is recommended that insulated bus wires be used and that the insulation be cut away at point of connection with the blasting cap series. To assure equal current distribution to each series, one bus wire should be reversed as shown in figure 4. With parallel series circuits, 14 gage or heavier gage connecting wire is used to reduce the total circuit resistance.

The third type of blasting circuit is the straight parallel circuit. The straight parallel circuit is less desirable to use than the series or series parallel circuits for two reasons. First, its nature is such that it cannot be checked. Broken leg wires or faulty connections cannot be detected once the circuit has been hooked up. Second, because the available current is divided by the number of caps in the circuit, powerline firing must often be used to provide adequate current for large parallel circuits. The problems associated with powerline firing will be discussed later.

Parallel circuits are not appropriate for surface blasting but they are used to some extent for tunnel blasting. Parallel circuits are similar to parallel series except that instead of each end of a series circuit being connected to alternate bus wires, each leg wire of each cap is connected directly to the bus wires, as shown in figure 4. In underground blasts using parallel circuits, bare bus wire is usually strung on wooden pegs driven into the face to avoid grounding. As with parallel series circuits, the bus wires are reversed as shown in figure 4.

In a parallel circuit the lead wire (firing line) represents the largest resistance in the circuit. Keeping the lead wire as short as possible, consistent with safety, is the key to firing large numbers of caps with parallel circuits. Doubling the length of the lead wire reduces the number of caps that can be fired by almost half. Heavy (12 to 14

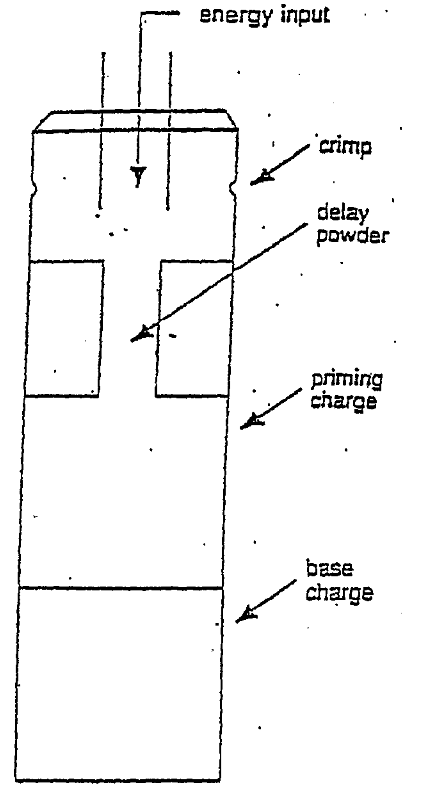

Figure 2. Delay detonator.

duce the resistance. A 14-gage connecting wire, rather than a lighter gage, is recommended to reduce the circuit resistance.

> ...machines should be operated vigorously to the end of the stroke because the current flows only at the end of the stroke. Because the condition of a generator blasting machine deteriorates with time, it is important that the machine be periodically checked with a rheostat designed for that purpose. The directions for testing with a rheostat are contained on the rheostat case or on the rheostat itself

CIRCUIT CALCULATIONS

Only the very basics of circuit calculations are covered here. For more detail on circuit calculations or other of the many intricacies of electrical blasting the reader should refer to a detailed electric blasting handbook such as reference 2. Figure 5 shows the resistance calculations for cap circuits for series, parallel series, and straight parallel circuits.

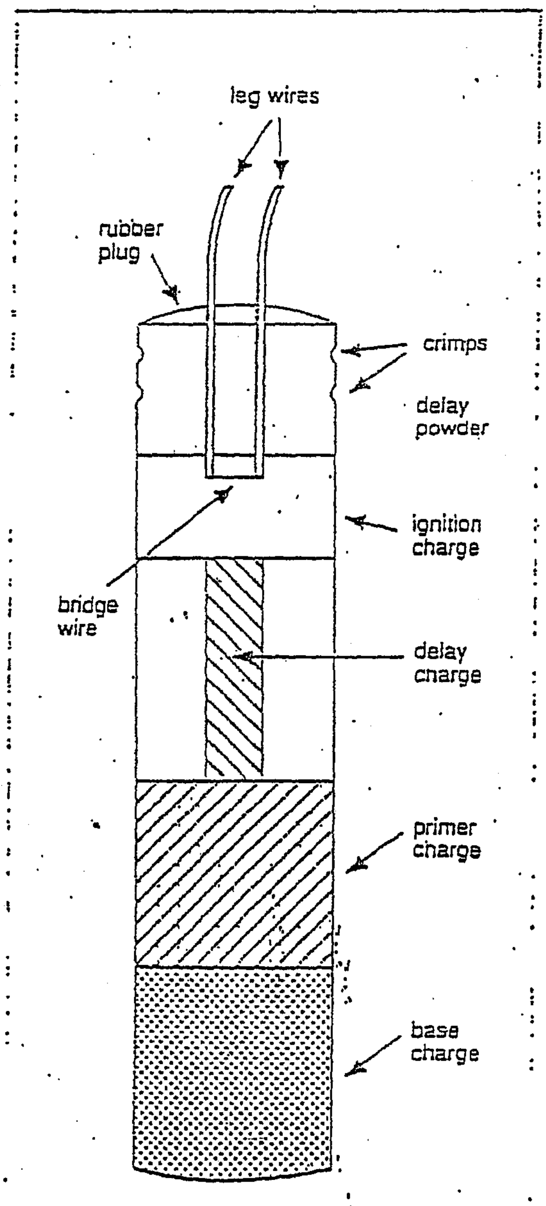

Figure 3. Delay electric blasting cap.

The resistance of a series circuit is the easiest to calculate. First, the resistance of a single cap, as specified by the manufacturer, is multiplied by the number of caps to determine the resistance of the cap circuit. To this is added the resistance of the connecting wire and that of the firing line to determine the resistance of the total circuit. Since the firing line contains two wires, there will be 2 ft of wire for every foot of firing line. Where bus wire is used (parallel or parallel series circuits) the resistance of one-half of the length of the bus wire is added to find the total circuit resistance. When firing from a powerline, the voltage of the line divided by the resistance of the circuit will give the current flow. In a single series circuit, all of this current flows through each cap. The minimum recommended firing current per cap is 1.5 amp dc or 2.0 amp ac. The current output of condenser (capacitor) discharge blasting machines may vary with the circuit resistance, but not linearly. Manufacturer's specifications must be consulted to determine the amperage of a specific machine across a given resistance. For a generator blasting machine, the manu- ... the machine in terms of the number of caps it can fire.

The resistance calculation for a parallel series circuit is as follows. First the resistance of each cap series is calculated as previously described. Remember, in a good parallel series circuit the resistance of each series should be equal. The resistance of a single series is then divided by the number of series to find the resistance of the cap circuit. To this are added the resistance of half the length of bus wire used, the resistance of the connecting wire, and the resistance of the firing line, to obtain the total circuit resistance. The locations of the bus wire, connecting wire, and firing line are shown in figure 4. The current flow is determined either by dividing the powerline voltage by the circuit resistance or in the case of a condenser discharge machine, by checking the manufacturer's specifications. The current flow is divided by the number of series to determine the current flow through each series.

For straight parallel circuits, the resistance of the cap circuit is equal to the resistance of a single cap divided by the number of caps. As can readily be seen, this is usually a very small value. For 20 short leg wire caps, the resistance is less than 0.1 ohm. The resistance of the connecting wire, the firing line, and one-half the bus wire are added to find the total resistance. The current flow is determined in the same manner as with series and parallel series circuits. The current flow is divided by the number of caps to determine the current flow through each cap.

POWER SOURCES

Electric blasting circuits can be energized by generator-type blasting machines, condenser-discharge blasting machines, and powerlines. Storage and dry cell batteries are definitely not recommended for blasting because they

... blasting machines may be of the rack-bar (push down) or the key-twist type. The capacity of rack-bar machines ranges from 30 to 50 caps in a single series, while key-twist machines will normally initiate 10 or 20 caps in a single series. The actual current put out by these machines depends on the condition of the machine and the effort exerted by the shotfirer. When using a rack-bar machine, the terminals should be on the opposite side of the machine from the operator. Both the rack-bar and twist machines should be operated vigorously to the end of the stroke because the current flows only at the end of the stroke. Because the condition of a generator blasting machine deteriorates with time, it is important that the machine be periodically checked with a rheostat designed for that purpose. The directions for testing with a rheostat are contained on the rheostat case or on the rheostat itself. Although the generator machine has been a dependable blasting tool, its limited capacity and variable output have caused it to be replaced, for most applications, by the condenser (capacitor) discharge machine.

As the name implies, the capacitor discharge (CD) machine employs dry cell batteries to charge a series of capacitors. The energy stored in the capacitor is then discharged into the blasting circuit. CD machines are available in a variety of designs and capacities, with some capable of firing over 1,000 caps in a parallel series circuit.

All CD machines operate in basically the same manner. One button or switch is activated to charge the capacitors and a second button or switch is activated to fire the blast. An indicator light or dial indicates when the capacitor is charged to its rated capacity. Ideally, the overall conditions of a CD blasting machine should be checked with an oscilloscope. However, the current output can be checked by using a specially designed setup combining a rheostat and a resistor (1) or by using a capacitor discharge checking machine (3). The powder supplier should be consulted as to the availability of machines for checking capacitor discharge machines.

A sequential blasting machine is a ... up to 10 separate circuits with a preselected time interval between the individual circuits. When used in conjunction with millisecond delay electric blasting caps, the sequential machine provides a very large number of separate delay intervals (2). This can be useful in improving fragmentation and in controlling ground vibrations and airblast. Because blast pattern design and hookup can be quite complex, the sequential blasting machine ... persons or under the guidance of a consultant or a powder company representative. A poorly planned sequential timing pattern will result in poor fragmentation and excessive overbreak, flyrock, ground vibrations, and noise.

The third alternative for energizing electric blasting circuits is the powerline. Powerline blasting is often done with parallel circuits where the capacity of available blasting machines is inadequate. When firing off a powerline,

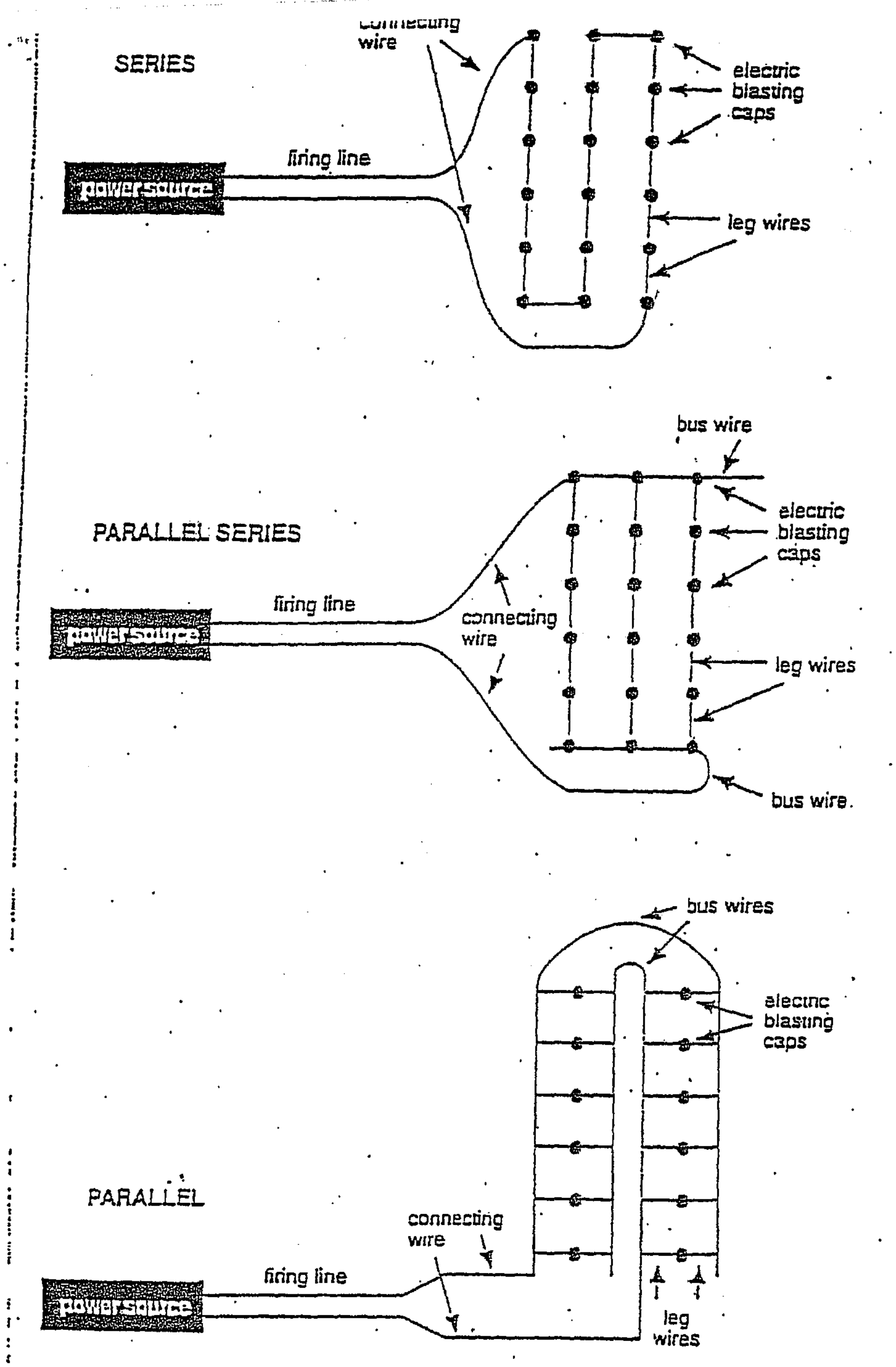

Figure 4. Types of electric blasting circuits.

the line should be dedicated to blasting alone, should contain at least a 15-ft lightning gap, and should be visually checked for damage and for resistance on a regular basis. Powerline shooting should not be done unless precautions are taken to prevent arcing. Arcing can result in erratic timing, a hangfire, or a misfire.

Arcing in a cap results from excessive heat buildup, which is caused by too much current applied for too long a period of time. A current of 10 amp or more continuously applied for a second or more can cause arcing. To guard against arcing the blaster may either use a blasting switch in conjunction with the powerline or add a No. 1 period millisecond delay cap, placed in a quarter stick of explosive, to the circuit and connecting wires leading to the cap circuit. An even better solution, if possible, is to use a high-output capacitor discharge machine to fire the shot, using a parallel series circuit if necessary.

CIRCUIT TESTING

It is important to check the resistance of the blasting circuit to make sure that there are no broken wires or short circuits and that the resistance of the circuit is compatible with the capacity of the power source. There are two types of blasting circuit testers; a blasting galvanometer (actually an ohmmeter) and a blasting multimeter. The blasting galvanometer is used only to check the circuit resistance, whereas a blasting multimeter can be used to check resistance, ac and dc voltage, stray currents, and current leakage (1). Only a meter specifically designed for blasting should be used to check blasting circuits. The output of such meters is limited to 0.05 amp, which will not detonate an electric blasting cap, by the use of a silver chloride battery and/or internal current-limiting circuitry.

Other equipment such as a "throw-away" go-no go device for testing circuits and a continuous ground current monitor is available. The explosive supplier should be consulted to determine what specific electrical blasting accessory equipment is available and what equipment is needed for a given job.

It is generally recommended that each component of the circuit be checked as hookup progresses. After each component is tested, it should be shunted. Each cap should be checked after the hole has been loaded and before stemming. In this way, a new primer can be inserted if a broken leg wire is detected. A total deflection of the circuit tester needle (no resistance) indicates a short circuit. Zero deflection of the needle (infinite resistance) indicates a broken wire. Either condition will prevent a blasting cap, and possibly the whole circuit, from firing.

Before testing the blasting circuit, its resistance should be calculated. After resistance of the circuit is checked and compared with the calculated value. A zero deflection at this time indicates a broken wire or a missed connection and an excessive deflection indicates a short circuit between two wires.

the two wires at one end of the line are shunted and the other end is checked with a blasting meter. A large deflection indicates that the firing line is not broken; a zero deflection indicates a broken wire.

After the circuit resistance has been checked and compared, the connecting wire is then added and the circuit is checked again. If a parallel series circuit is used, the change in resistance should be checked as each series is added to the bus wire. In a straight parallel circuit, a break in the bus wire can sometimes be detected. However, a broken or a shorted cap wire cannot be detected in a straight parallel circuit because it will not affect the resistance significantly.

A final check of the circuit is made at the shotfirer's location after the firing line has been connected. If a problem is found in a completed circuit, the circuit should be broken up into separate parts and checked to isolate the problem. The firing line should be checked for a break or a short after each blast, or at the end of each shift as a minimum.

To check for a break in the firing line, the two wires at one end of the line are shunted and the other end is checked large deflection indicates that the firing line is not broken; a zero deflection indicates a broken wire. To test for a short, the wires at one end of the lead line are separated and the other end is checked with the meter. A zero deflection should result. If there is a deflection, the lead line has a short circuit. Embarrassing, hazardous, and costly misfires can be avoided through proper use of the blasting galvanometer or blasting multimeter.

Certain conditions such as damaged insulation, damp ground, a conductive ore body, water in a borehole, bare wires touching the ground, or bulk slurry in the borehole may cause current to leak from a charged circuit. Although this is not a common occurrence, you may want to check for it if you are experiencing unexplained misfires. To properly check for current leakage you should check with a consultant or an electric blasting handbook (1). Measures for combating current leakage include using fewer caps per circuit, using heavier gage lead lines and connecting wires, keeping bare wire connections from touching the ground, or using a nonelectric initiation system.

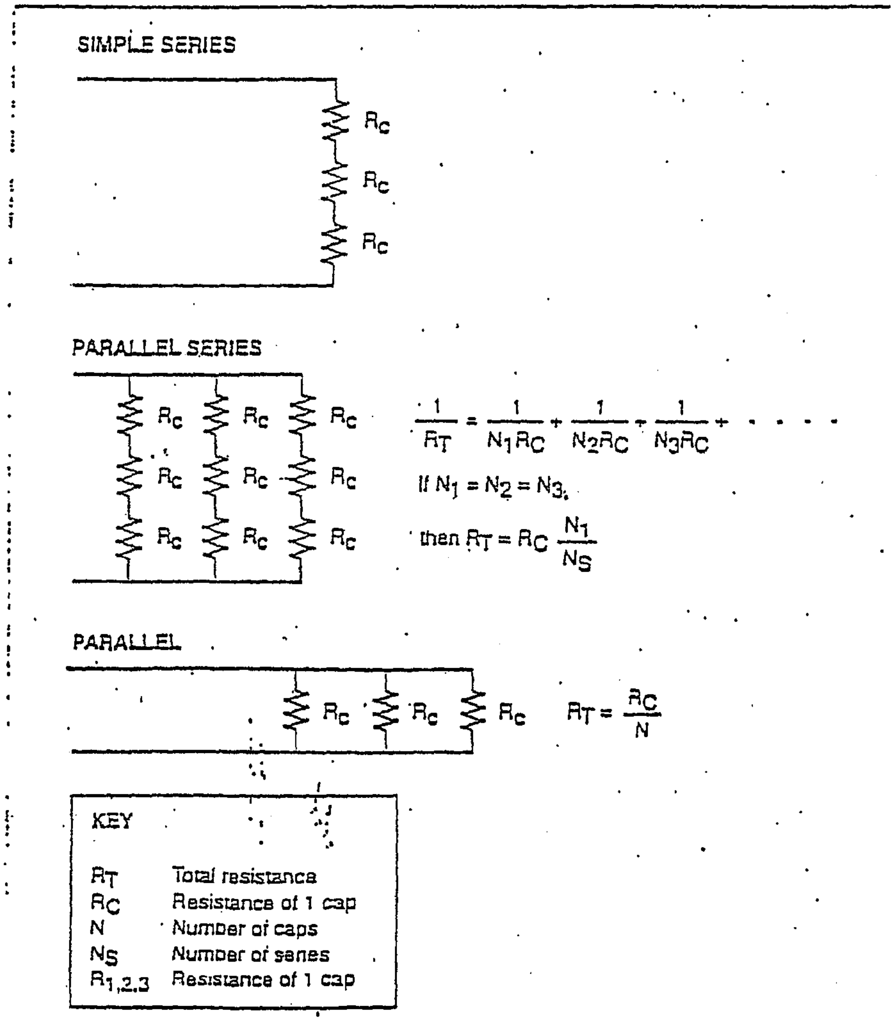

Figure 5. Calculation of cap resistance circuits.

EXTRANEOUS ELECTRICITY

The principal hazard associated with electric blasting systems is lightning. Extraneous electricity in the form of stray currents, static electricity, and radio-frequency energy, and from high-voltage powerlines can also be a hazard. Electric blasting caps should not be used in the presence of stray currents of 0.05 amp or more. Stray currents usually come from heavy equipment or power systems in the area, and are often carried by metal conductors or high-voltage powerlines. Atlas (1) outlines techniques for checking for stray currents. Instruments have recently been developed which continuously monitor ground currents and sound an alarm when an excess current is detected. The supplier should be consulted as to the availability of these units.

pneumatic loading, particles carried by high winds, particularly in a dry atmosphere, and by rubbing of a person's clothes. Most electric blasting caps are static resistant. When pneumatically loading blasting agents with pressure pots or venturi loaders, a semi-conductive loading hose must be used, a plastic borehole liner should not be used, and the loading vessel should be grounded.

Electrical storms are a hazard regardless of the type of initiation system being used. Even underground mines are susceptible to lightning hazards. Upon the approach of an electrical storm, loading operations must cease and all personnel must retreat to a safe location. The powder manufacturer should be consulted on the availability of commercial storm warning devices. Some operators use static on an AM radio as a crude detector of approaching storms. Weather reports are also helpful.

Broadcasting stations, mobile radio transmitters, and radar installations present the hazard of radio-frequency energy. The IME (5) has prepared charts giving transmission specifications and potentially hazardous distances.

High-voltage powerlines present the hazards of capacitive and inductive coupling, stray current, and conduction of lightning.

Atlas (1) details precautions to be taken when blasting near high-voltage powerlines. A specific hazard with powerlines is the danger of throwing part of the blasting wire onto the powerline. This shorts the powerline to the ground and has been responsible for several deaths. Care should be exercised in laying out the circuit so that the wires cannot be thrown on a powerline. Other alternatives are to weigh down the wires so they cannot be thrown or attach a charge that cuts the blasting wire.

ADDITIONAL CONSIDERATIONS

Electric blasting is a safe, dependable system when used properly under the proper conditions. Advantages of the system are its reasonably accurate delays, ease of circuit testing, control of blast initiation time, and lack of airblast or disruptive effect on the explosive charge. In addition to extraneous electricity, one should guard against kinks in the cap leg wires, which can cause broken wires, especially in deep holes. Different brands of caps may vary in electric properties, so only one brand per blast should be used. It is recommended that the blaster carry the key or handle to the power source on his or her person so the shot cannot be inadvertently fired while he or she is checking out the shot.

A device called an exploding bridge wire is available for use where a single cap is used to initiate a non-electric circuit. This device has the safety advantages of a lack of primary explosive in the cap and a high voltage required for firing. A special firing box is required for the system. The high power required and high cost of the exploding bridge wire device make it unsuitable for use in multi-cap circuits.

DETONATING CORD INITIATION

Detonating cord initiation has been used for many years as an alternative to electric blasting where the operator prefers not to have an electric initiator in the blasthole. Detonating cord consists of a core of high explosive, usually PETN, contained in a waterproof plastic sheath enclosed in a reinforcing covering of various combinations of textile, plastic, and waterproofing. Detonating cord is available with PETN core loadings ranging from 1 to 400 gr/ft.

All cords can be detonated with a blasting cap and have a detonation velocity of approximately 21,000 fps. Detonating cord is adaptable to most surface blasting situations. When used in a wet environment the ends of the cord should be protected from water. PETN will slowly absorb water and as a result will become insensitive to initiation by a blasting cap. Even when wet, however, detonating cord will propagate if initiated on a dry end. Understanding the function of a detonating cord initiation system requires a knowledge of the products available. The Ensign-Bickford Co. has published a manual (4) that describes detonating cord products in detail. Technical data sheets are available from Austin Powder Co. and Apache Powder Co.

DETONATING CORD PRODUCTS

The most common strengths of detonating cord are from 25 to 60 gr/ft. These strengths are used for

(See Back to Basics, page 52)

(100 Years Ago, cont'd page 51)

direct itself out of the machine. An operative receives the cartridges upon their exit, wraps them in paper, and closes the two extremities. These cartridges are afterward carried to the packing room and put into cases, as we have already said.

It now remains for me to tell you the composition of the famous nitro-glycerine, which, up to the present, seems to be, as it is in fact, the explosive constituent of what is called dynamite (from the Greek, δυναμις, power). If you will refer to our engravings, you will find very faithfully represented therein the industrial manufacture of this mysterious nitro-glycerine.

The huge cylinder (which is of lead) that you see in our first figure contains the terrible mixture of nitric and sulphuric acids and glycerine, the chemical reaction of which forms nitro-glycerine. The array of pipes that end at the cylinder, or empty themselves at the top, are the ones that lead each of these constituents to the interior of the apparatus, or that conduct the water designed to cool the mixture in order to prevent explosions due to ill-timed elevations of the temperature. In Fig. 1, a workman is placidly collecting the oily and explosive liquid, a glassful of which would suffice to blow him to atoms. This valuable and sometimes criminal liquid is carried to the room represented in Fig. 3, where it is mixed with a silicious powder. It is then kneaded until the nitro-glycerine is absorbed by the powder. . . The paste thus formed is that which we have just seen put into cartridges, which are afterward sent to the magazines, whence they are shipped to the industries.— *Maxime Vuillaume, in L'Illustration.*

RBEI NOTE: This article, about a dynamite manufacturing plant in 1895, also refers to the St. Gothard tunnel job of the 1870s. The writer implies that the tunnel project was possible only because of the availability of dynamite. In actuality, the job could have been done with the long-available black powder, but it would have taken many more years and would certainly have been much more costly from both the monetary and accident standpoints. It's easy for those of us who have never known the industrial world without high explosives to forget that, without their invention, most large rock-excavation projects would be impossible or at least highly impractical.

The illustrations show the rudimentary dynamite-packing methods of that time, but the principles they show remain unchanged today: using a tamp-stick in the case of free-running or semi-gelatinous dynamites, and an extruder for the gelatins. The difference today is that the processes are carried out by machines, processing many cartridges simultaneously, rather than by individual labor filling one or two at a time, with separate wrapping and crimping operations.

The "explosive gum" referred to would today be called "blasting gelatin."

>JEE<

(Back to Basics, cont'd from page 37)

trunklines, which connect the individual blastholes into pattern, and for downlines, which transmit the energy from the trunkline to the primer cartridge. The lower strength cords are cheaper, but some have less tensile strength and may be somewhat less dependable under harsh field conditions. Some cast primers are not dependably initiated by 25-gr cord or lighter cord. However, under normal conditions, the lighter core loads offer economy and their greater flexibility makes field procedures such as primer preparation and knot tying easier. Detonating cord strengths of 100 to 200 gr/ft are occasionally used where continuous column initiation of a blasting agent is desired. Cords with 200 to 400 gr of PETN per foot are occasionally used as a substitute for explosive cartridges in very sensitive or small, controlled blasting jobs.

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BACK TO BASICS: BLASTHOLE LOADING

by
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Blasthole loading involves placing all of the necessary ingredients into the blasthole, including the main explosive charge, deck charges, initiation systems, primers, and stemming. Blasthole loading techniques vary depending on borehole diameter, type of explosive, and size of the blast. For the purpose of this discussion, boreholes have been arbitrarily classified as small diameter (>4 in.) and large diameter (<4 in.). Small-diameter boreholes may be drilled at practically any inclination from vertically down to vertically up. Large-diameter blastholes are usually drilled vertically down, but in some cases are angled or horizontal.

As a specific precaution, blastholes should never be loaded during the approach or progress of an electrical storm. General descriptions of blasthole loading procedures are in the literature (2-5).

CHECKING THE BLASTHOLE

Before loading begins, the blastholes should be checked. Depending on the designed depth, either a weighted tape measure or a tamping pole should be used to check that the boreholes are at the proper depth. If a hole is deeper than the plan calls for, drill cuttings or other stemming material should be used to bring the bottom of the hole up to the proper level. Loading an excessively deep blasthole is a waste of explosive and usually increases ground vibrations. Boreholes that are less than the planned depth should either be cleared out with the drill or compressed air, or redrilled. Sometimes economics or equipment limitations may dictate that a shot be fired with a few short holes. The blasting foreman should make this decision.

Occasionally a borehole may become obstructed. On a sunny day, a mirror may be used to check for obstructions. Obstructions in small holes may sometimes be dislodged with a tamping pole. In large, vertical holes, a heavy weight suspended on a rope and dropped repeatedly on the obstruction may clear the hole. It may be necessary to use the drill string to clear a difficult obstruction or, if the obstruction cannot be cleared, redrilling may be necessary.

If it is necessary to redrill a hole adjacent to a blocked hole, the blocked hole should be filled with stemming. If this is not done, the new hole may shoot into the blocked hole and vent, causing excessive flyrock, airblast, and poor fragmentation. A hole must not be redrilled where there is a danger of intersecting a loaded hole.

While checking the hole for proper depth, it is convenient to check for water in the borehole. With just a little experience, the blaster can closely estimate the level of water in a borehole by visually checking the tamping pole or weighted tape for wetness after the borehole depth check has been made. To get a more accurate check, the weighted end of the tape can be jiggled up and down at the water level. A splashing sound will indicate when the weight is at the water level.

A blasthole may pass through or bottom into an opening. Where this opening is not unduly large, it may be filled with stemming material (fig. 1). Where the opening is too large for this to be practical, the hole must either be left unloaded, redrilled in a nearby location, or plugged.

A simple method for plugging a blasthole is as follows. A stick is tied to the end of a rope, lowered into the void, and pulled back up so it lodges crosswise across the hole. The rope is staked securely at the borehole collar. Bulky materials such as empty powder bags or rags are then dropped down the hole, dirt is then shoveled down the hole to form a solid bottom, after which explosive loading can proceed. Where voids are commonplace, you may want to develop a tailor-made borehole plugging device.

In some districts hot holes may be encountered, although this is not very common. Hot holes may occur in anthracite mining or other areas of in situ coal seam fires. If there is reason to suspect a hot hole, the hole can be checked by suspending a thermometer in it for a few minutes. Explosive materials should not be loaded into holes hotter than 150° F.

GENERAL LOADING PROCEDURES

Blastholes may be loaded with bulk or packaged products. Bulk products are either poured into the hole, augered, pumped, or blown through a loading hose. Packaged products are either dropped into the hole, pushed in with a tamping pole or other loading device, or loaded through a pneumatic tube. It is a good idea to check the rise of the powder column frequently as loading progresses, using a tamping pole, weighted tape, or loading hose. This will give warning of a cavity or oversized hole that is causing a serious overcharge of explosive to be loaded, and will also assure that sufficient room is left at the top of the hole for the proper amount of stemming. When the powder column has reached the proper location, the primer is loaded into the borehole. It is important that the wires, tubes or detonating cord leading from the primer are properly secured at the vertical holes, using a rock or stake.

In almost all situations it is recommended that the explosive charge be totally coupled. Total coupling means that the charge completely fills the borehole diameter. Bulk loading of explosives assures good coupling. When cartridged products are used, coupling is improved by slitting the cartridges and tamping them firmly into place. There are four situations where cartridges or packages of explosives should not be tamped.

1. In permissible coal mine blasting, where deforming the cartridge is against regulations.

2. In controlled blasting, where string loads or even gaps between cartridges are used to reduce the charge load in the perimeter holes to prevent shattering.

3. In water, where the package serves as protection for a non-water resistant explosive product.

4. A primed cartridge is never tamped.

It is recommended that all blastholes be stemmed to improve the efficiency of the explosive and to reduce airblast and flyrock. As a rule of thumb, the length of stemming should be from 14 to 28 times the borehole diameter. Sized crushed stone makes the most efficient stemming. However, for reasons of economy and convenience, drill cuttings are most commonly used. Large rocks should never be used as stemming as they could become a dangerous source of flyrock and may also damage the wires, cord, or tubes of the initiation system. Because it is inconvenient to stem horizontal holes, horizontal rounds are sometimes left unstemmed, although it is recommended that all blastholes be stemmed to improve blasting efficiency. By regulation, underground coal mine rounds must be stemmed with noncombustible stemming such as water-filled cartridges or clay "dummies."

Care must be exercised in using detonating cord downlines in relatively small blastholes.

One solution to blasting in wet boreholes is to use a water-resistant explosive. However, economics often favor dewatering the blasthole and loading it with ANFO inside a protective plastic borehole liner. Although dewatering has been used mostly in large-diameter holes, it can be used in diameters below 4 in. To dewater, a pump is lowered to the bottom of the hole. When the water has been removed, the hole is lined with a plastic sleeve as follows. A roll of hollow plastic tubing is brought to the collar of the hole. A rock is placed inside the end of the tubing and a knot is tied in the end of the tubing to hold the rock in place. The tubing is reeled into the borehole, and care is taken not to tear it. The tubing is cut off at the collar, allowing 4 to 6 ft. extra for charge settlement. The ANFO and primer are loaded inside the tubing and the hole is stemmed. Where water is seeping into the borehole, it is important that the tubing and ANFO be loaded quickly to prevent the hole from refilling with water.

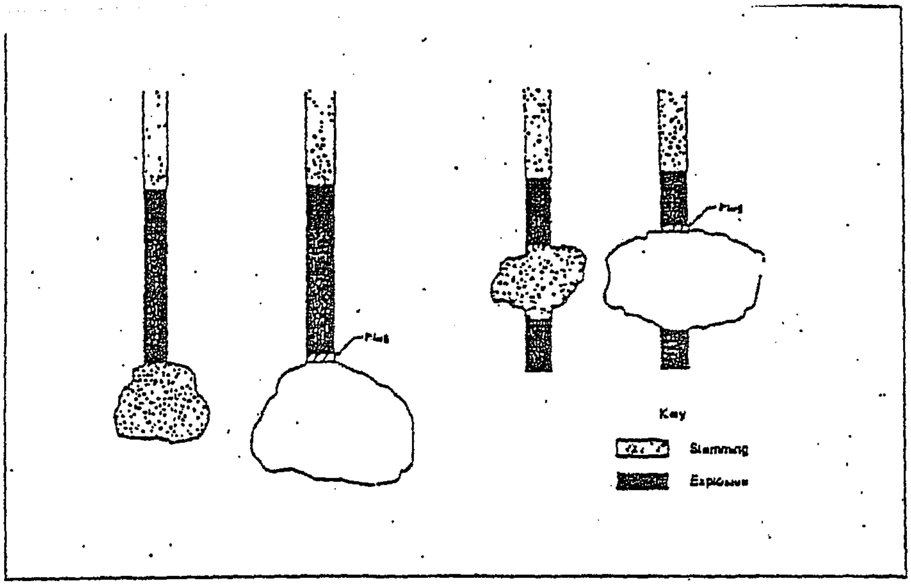

Figure 1. Corective measures for voids.

SMALL-DIAMETER BLASTHOLES

When small-diameter blastholes are loaded, the primer cartridge is normally loaded at the bottom of the hole. This gives maximum confinement at the point of initiation and also guards against leaving undetonated explosive in the bottom of the borehole if it should become plugged during loading or cut off during the blasting process. Some experts condone, or even recommend a cushion stick or two, but the general recommendation is not to use a cushion stick.

To avoid having the detonator fall out of the primer cartridge, the cartridge should never be slit, rolled, or otherwise deformed. The primer cartridge should never be tamped.

CARTRIDGED PRODUCTS

Cartridged dynamites and slurries (water gels) are commonly used in small-diameter blastholes. These cartridges are usually slit, loaded by hand, and tamped to provide maximum coupling and loading density. One or two cartridges should be loaded after the primer before tamping begins. Tamping should be done firmly, but not excessively. Using the largest diameter cartridge compatible with the borehole diameter will increase coupling and loading density.

Pneumatic systems for loading water gel cartridges are available. The cartridges are propelled through a loading hose at high velocity at a rate of up to one cartridge per second. The cartridges are automatically slit as they enter the blasthole and each cartridge splits upon impact. Because of the high impact imparted to the cartridges, loading dynamites with this type of loading system is not permitted. Pneumatic cartridge loaders are especially useful in loading holes that have been drilled upward.

BULK DRY BLASTING AGENTS

Bulk dry blasting agents, usually ANFO, may be loaded into small-diameter blastholes by pouring from a bag or by pneumatic loading through a loading hose. Poured charges in diameters less than 4 in. lose some efficiency because of ANFO's low density and its reduced detonation velocity at small diameters. As with all bulk loading, good coupling is achieved. Caution should be exercised in using pourec ANFO charges in diameters less than 3 in. This should be done only unde bone-dry conditions because ANFO's efficiency begins to drop significantly at this point, and water will compounc the problem.

Pneumatic loading of ANFO in small holes is recommended because of ease of handling, faster loading rates, and the improved performance of the ANFO caused by partial pulverizing of the prills, which gives a higher loading density and greater sensitivity *(1, 4)*. The two basic types of pneumatic loading systems are the pressure vessel and the ejector or venturi-type loader.

A pressure vessel type ANFO loader should have a pressure regulator so that the tank pressure does not exceed the manufacturer's recommendation, usually 30 psi. This low-pressure type loader propels the prills into the borehole at a low velocity and high volume rate, loading the ANFO at a density slightly above its poured density with a minimum amount of prill breakage. In a pressure vessel, the compartment containing the

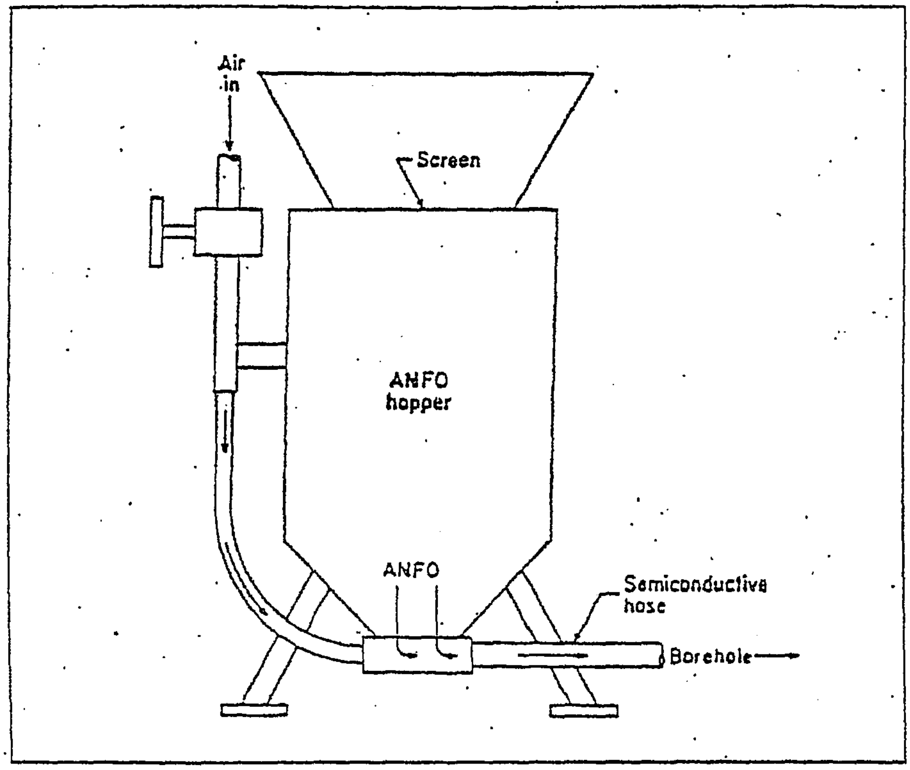

Figure 1. Ejector-type pneumatic ANFO loader.

ANFO is under pressure during loading. Loading rates of over 100 lb./min. can be achieved with some equipment and pressure vessels with ANFO capacities of 1,000 lb. are available. The smaller and more portable pressure vessel loaders have loading rates of 15 to 50 lb./min. and ANFO capacities of 75 to 200 lb. Pressure vessels larger than 1 cu. ft. in volume should meet ASME specifications for construction.

The ejector-type system (fig. 2) uses the venturi principle to draw ANFO from the bottom of an open vessel and propel it at a high velocity but low volume rate into the borehole, pulverizing the prills and giving bulk loading densities near 1.00. Ejector systems operate from line pressures of 40 to 80 psi and load at rates of 7 to 10 lb/min. Combination loaders are available that force feed a venturi from a pressurized pot. This system gives the same high loading density and prill breakage as the straight venturi loader with an increase in loading rate. Specifications of pneumatic loading systems are given in Table 1. The detonation velocity of ANFO as a function of charge diameter for poured and pneumatically loaded charges is shown in Figure 3. The benefits of high-velocity pneumatic loading are significant at small borehole diameters.

A problem may arise where a high-pressure ejector loader is used to load ANFO in small holes in soft formations such as uranium ore. The pulverized prills may be dead pressed by the compression from adjacent charges fired on earlier delays. This can cause the ANFO not to fire.

Static electricity can be a hazard when loading ANFO pneumatically into small-diameter boreholes. Static electricity hazards can be reduced by using antistatic caps or nonelectric initiators. A semiconductive hose with a minimum resistance of 1,000 ohms/ft and 10,000 ohms total resistance, and a maximum total resistance of 2,000,000 ohms for the entire system, should be used. The pneumatic loader should be properly grounded.

Homemade loading equipment should not be used. All equipment should be operated at the proper pressure. Gaps in the powder column can be avoided by keeping the hopper full and maintaining a constant standoff distance between the end of the loading hose and the column of ANFO. Loading proficiency improves through operator experience.

The pneumatic loading tube is useful for blowing standing drill water from a horizontal borehole. However, if the borehole is "making water," external protection for the ANFO by means of a plastic sleeve is required. Loading inside a plastic borehole sleeve is not recommended for underground work because of the static electricity hazard during loading and toxic fumes generated during blasting. If plastic-sleeve protection with pneumatic loading in well-ventilated locations is required, a nonelectric detonating system should be used because the insulating effect of the sleeve is likely to cause a buildup of static electricity.

BULK SLURRIES

Slurries may be bulk loaded into blasthole diameters as small as 2 in. These products are frequently poured from bags, but occasionally bulk pumping units are used. The sensitivity of slurries, and hence the diameter at which they may be effectively used, depends largely on their formulation. The use of bulk slurries in diameters below those intended for the product can result in substandard blasts or misfires. The manufacturer should be consulted when loading bulk slurries into small-diameter blastholes.

PERMISSIBLE BLASTING

Loading blastholes in underground coal mines is strictly regulated by MSHA in order to prevent ignition of explosive atmospheres. Only permissible explosives may be used in underground coal mines. Certain nitroglycerin-based explosives, emulsions, slurries, and water gels have been certified as permissible by MSHA *(6)*.

The primer plus the remaining cartridges are stringloaded and pushed back into the hole as a single unit to avoid getting coal dust between the cartridges. Charge weights may not exceed 3 lb per borehole. Black powder, detonating cord, and ANFO are not permissible. Blastholes are initiated with copper alloy shell electric blasting caps. All holes must be stemmed with noncombustible material such as water bags or clay dummies. The stemming length must be at least 24 in. or one-half the depth of the borehole, whichever is less. Permissible blasting procedures are also required for gassy noncoal mines, but are frequently less stringent than for coal mines.

LARGE-DIAMETER BLASTHOLES

With few exceptions, economics and efficiency favor the use of bulk loading in blasthole diameters larger than 4 in. The products are cheaper, loading is faster, and the well-coupled bulk charge gives better blasting efficiency. Large-diameter blastholes may be top, center, or toe primed, or multiple primers may be used.

PACKAGED PRODUCTS

Large diameter dynamite cartridges are seldom used today except for occasional use as primers. ANFO and slurries give better economy in large-diameter blastholes. When wet boreholes are encountered and the operator wants to use ANFO, water-resistant polyburlap packages of partially pulverized, densified ANFO are used. Densification is necessary so that the packages will sink in water. ANFO packages should be carefully lowered into water-filled holes rather than dropped, because a broken bag will result in desensitized ANFO, an interruption in the powder column, and, most likely, some unfired ANFO. A disadvantage of waterproof ANFO packages is that some borehole coupling is lost. Also the heat lost to the water will reduce the energy released. Where it is desired to use ANFO in wet boreholes, the option of borehole dewatering should be investigated.

Slurries are available in polyethylene packaging in diameters up to 8 in. Some of these products are semirigid and others are in dimensionless bags that will slump to fit the borehole diameter. With the semirigid cartridges, the advantage of borehole coupling is lost.

BULK DRY BLASTING AGENTS

Bulk loading offers significant advantages over loading of packaged products in large-diameter blastholes, including cheaper products, faster loading, and better use of the available space in the borehole.

The bulk ANFO or prills are stored in overhead storage bins, from which they are loaded into the bulk trucks. The ANFO may be trucked to the blast site in premixed form or the oil may be metered into the prills as they are placed into the blasthole. Bulk loading systems for dry blasting agents (ANFO) may be of the auger or pneumatic type.

Auger loading gives the fastest loading rates. A side-boom auger is satisfactory for loading one row of holes at a time. Where it is desired to reach more holes from one setup, an overhead boom auger with a 350° radius of swing can be used. With this type of equipment, flexible tubing usually extends from the end of the auger boom to ground level. The amount of blasting

Table 1. Characteristics of pneumatically loaded ANFO in small-diameter blastholes.

Loading device	Jet Pressure, psi	Tank Pressure, psi	Loading Rate[1], lb/min	Loading density, g/cu cm
Pressure vessel	NAp	10-30	15-70	0.80-0.85
Ejector loader (jet)	40-80	NAp	7-10	.90-1.0
Combination loader	20-80	20	15-25	.9-1.0

NAp = Not Applicable
[1] = Values with hose diameter.

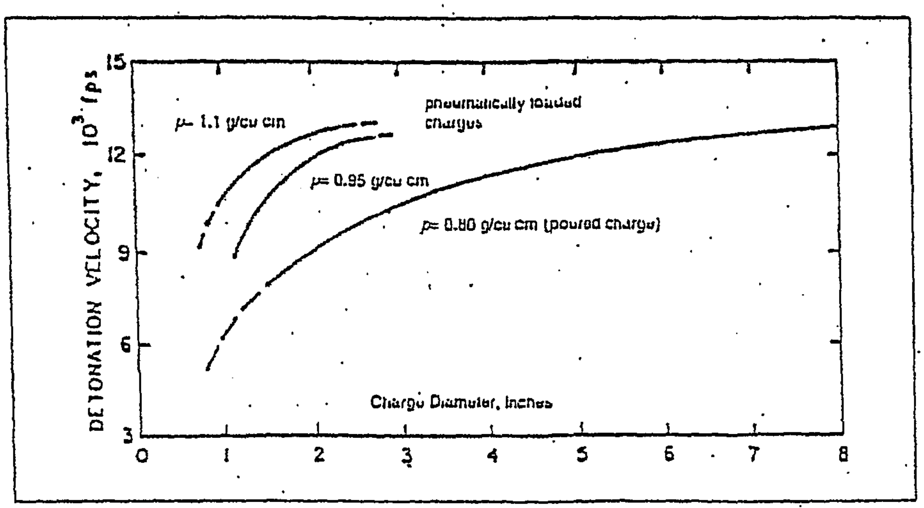

Figure 3. ANFO detonation velocity as a function of charge diameter and density.

agent delivered into the blasthole is sometimes indicated on a meter in the truck. In other situations a hopper with a given volume of capacity is hung at the end of the auger boom to measure the ANFO as it is loaded. Bulk loading trucks have capacities of from 2,000 to 30,000 lb of ANFO, and with auger systems can deliver up to 600 lb of ANFO per minute into a blasthole.

Pneumatic loading is also used in large-diameter boreholes. Pneumatic units are especially useful in rough terrain, where a long loading hose is used to load numerous blastholes from a single setup.

Hand pouring ANFO from 50-lb bags is still practiced at operations where the capital expense of a bulk system cannot be justified. This, of course, gives the same complete coupling as bulk loading.

BULK SLURRIES

Bulk slurry pumping is commonplace in large-diameter vertical hole blasting. Some slurry trucks have capacities of up to 30,000 lb of slurry and have typical pumping rates of 200 to 400 lb/min. A bulk slurry truck may bring a plant-mixed slurry to the borehole or it may carry separate ingredients for onsite mixing.

Onsite slurry mixing is more complex than ANFO mixing and is usually done by a competent explosive distributor rather than the consumer. Plant mixing permits closer quality control in the blending of ingredients, whereas onsite mixing permits different energy densities to be loaded from hole to hole or in different locations within a single hole.

The slurry is pumped as a liquid and a cross-linking ingredient is added just as the slurry enters the loading hose. Cross linking to a gelatinous consistency begins in the hose and is completed in the borehole. A meter on the bulk truck indicates the amount of slurry that has been loaded.

Hand pouring of slurry from polyethylene packages is still practiced at operations where the volume of slurry used does not justify a bulk-loading truck. Pouring, rather than loading the entire package, gives complete borehole coupling. >JEE<

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Note: Reference to specific trade names does not imply endorsement by the Bureau of Mines.

BACK TO BASICS: DETONATING CORD PRIMING

by
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Detonating cord initiation has been used for many years as an alternative to electric blasting where the operator prefers not to have an electric initiator in the blasthole. Detonating cord consists of a core of high explosive, usually PETN, contained in a waterproof plastic sheath enclosed in a reinforcing covering of various combinations of textile, plastic, and waterproofing. Detonating cord is available with PETN core loadings ranging from 1 to 400 gr/ft.

All cords can be detonated with a blasting cap and have a detonation velocity of approximately 21,000 fps. Detonating cord is adaptable to most surface blasting situations. When used in a wet environment the ends of the cord should be protected from water. PETN will slowly absorb water and as a result will become insensitive to initiation by a blasting cap. Even when wet, however, detonating cord will propagate if initiated on a dry end. Understanding the function of a detonating cord initiation system requires a knowledge of the products available. The Ensign-Bickford Co. has published a manual that describes detonating cord products in detail. Technical data sheets are available from Austin Powder Co.

DETONATING CORD PRODUCTS

The most common strengths of detonating cord are from 25 to 60 gr/ft. These strengths are used for trunklines, which connect the individual blastholes into pattern, and for downlines, which transmit the energy from the trunkline to the primer cartridge. The lower strength cords are cheaper, but some have less tensile strength and may be somewhat less dependable under harsh field conditions. Some cast primers are not dependably initiated by 25-gr cord or lighter cord. However, under normal conditions, the lighter core loads offer economy and their greater flexibility makes field procedures such as primer preparation and knot tying easier.

Detonating cord strengths of 100 to 200 gr/ft are occasionally used where continuous column initiation of a blasting agent is desired. Cords with 200 to 400 gr of PETN per foot are occasionally used as a substitute for explosive cartridges in very sensitive or small, controlled blasting jobs.

Detonating cord strengths lower than 25 gr/ft are sometimes used. Fifteen- to twenty-grain products may be used for small-diameter holes, for secondary blasting, and in the Nonel system. A 7.5-gr cord is also used in the Nonel system. A 4-gr/ft product is used as part of an assembly called a Primaline Primadet. A Primaline Primadet consists of a length of 4-gr cord crimped to a standard instantaneous or delay blasting cap. The cap is inserted into the primer and the 4-gr cord serves as a downline. Various cord lengths are available to suit specific borehole depths. These Primadets are primarily used in underground mines, such as salt, where Nonel tubes would be a product contaminant. Du Pont's new Detaline System utilizes a 2.4-gr cord.

Millisecond delay surface connectors are used for delaying detonating cord blasts. To place a delay between two holes, the trunkline between the holes is cut and the ends are joined with a delay connector. One type of delay connector is a plastic assembly containing a delay element. At each end of the element is an opening into which a loop of the severed trunkline can be inserted. A tapered pin is used to lock the trunkline cord into place. A Nonel delay connector has also been developed for detonating cord blasting. This connector consists of two plastic blocks, each containing a delay initiator, connected by a short length of Nonel tubing. Each end of the severed trunkline is wrapped around the notch in one of the plastic blocks. Both types of delay connector are bidirectional.

FIELD APPLICATION

After the primer has been lowered to its proper location in the blasthole, the detonating cord is cut from the spool. About 2 or 3 ft of cord should extend from the hole to allow for charge settlement and tying into the trunkline. When the entire shot has been loaded and stemmed, the trunkline is laid out along the path of desired initiation progression. Trunkline-to-trunkline connections are usually made with a square knot. A tight knot, usually a clove hitch, a half hitch, or a double-wrap half hitch, is used to connect the downline to the trunkline. Any excess cord from the downline should be cut off and disposed. If Primadets or other in-hole delay assemblies are used, a plastic connector often serves as the connection to the trunkline (Figure 1). The cord lines should be slack, but not excessively so. If too much slack is present, the cord may cross itself and possibly cause a cutoff (Figure 2). Also, if the lines are too tight and form an acute angle, the downline may be cut off without detonating.

Downlines of detonating cord can adversely affect the column charge of explosive in the blasthole. With cap-sensitive explosives, continuous, axial initiation will occur with any cord containing 18 or more grains of PETN per foot of cord. Lower strength cords may also cause axial initiation. Four-grain cord will not initiate most cap-sensitive sitized or it may be marginally initiated. Hagan has studied this problem. The effect depends on the cord strength, blasting agent sensitivity, blasthole diameter, and position of the cord within the blasthole. As a general rule, 50-gr cords are compatible with blasthole diameters of 8 in or more. In charge diameters of 5 to 8 in, 25-gr or lighter downlines should be used. In diameters below 5 in. low-energy (4- to 10-gr) downlines or alternative, nondisruptive initiation systems are recommended. The manufacturer should be consulted for recommendations on the use of detonating cord with various explosive products. A low-energy initiation system called Detacord, developed by du Pont, is described later in this article.

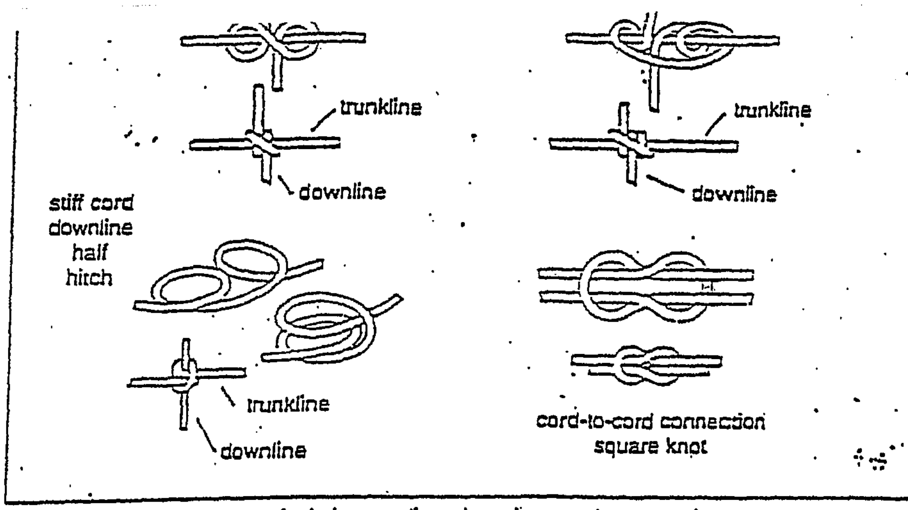


Figure 1—Recommended knots for the detonating cord.

DELAY SYSTEMS

Surface delay connectors offer an unlimited number of delays. For instance, a row of 100 holes could be delayed individually by placing a delay between each hole and initiating the row from one end. Typical delay intervals for surface connectors are 5, 9, 17, 25, 35, 45, and 65 ms. Since these connectors are normally used for surface blasting, half-second delay periods are not available.

Cutoffs may be a problem with surface delay connectors. When the powder column in one hole detonates, the connections between holes to be fired later may be broken by cratering or other movement of the rock mass. This may cause a subsequent hole to misfire. To correct this situation, MSHA requires that the pattern of trunklines and delay connectors be designed so that each blasthole can be reached by two paths from the point of initiation of the blast round. The patterns can become somewhat complex and should be laid out and carefully checked on paper before attempting to lay them out in the field. Where possible the pattern should be designed so that the delay sequence in which the holes fire is the same no matter which path is taken from the point of blast initiation. The "Blast Design" chapter gives suggestions for selecting the actual delay intervals between blastholes.

Figure 3 shows a typical blast laid out with delay connectors. Note that each hole can be reached by two paths from the point of initiation. A time of 1 ms is required for 21 ft of detonating cord to detonate. This time is not sufficient to significantly alter the delay interval between holes.

When detonating cord downlines are used, detonation of the cord in the blasthole proceeds from the top down. This presents two disadvantages. First, the detonation of the cord may have an undesirable effect on the column charge as it proceeds downward and the stemming may be loosened. Second, if the hole is cut off by burden movement caused by detonation of an earlier hole (Fig. 4) the powder in the lower portion of the hole will not detonate. The use of a Primaline Primadet delay unit in the hole will correct both of these problems.

The Primaline Primadet is a delay cap attached to a length of 4-gr/ft detonating cord. It is available in both millisecond and long delay periods. The Primaline Primadet is connected to the trunkline with a plastic connector or a double-wrap half hitch. If the delay pattern of the blast is such that the number of available Primadet delay periods is adequate, an undelayed trunkline may be used. The delay period of the cap would then be the delay period of the hole. As an example, to attain the delay pattern in Figure 3, cap

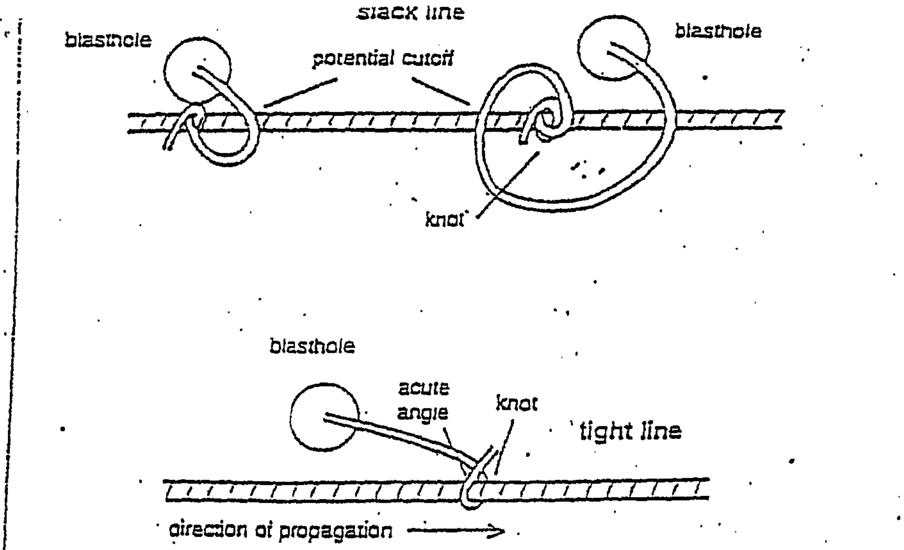


Figure 2—Potential cutoffs from slack and tight detonating cord lines.

delay periods one through nine would be placed in the appropriate holes and trunklines would contain no delays. In this situation, the delay in every cap would be actuated before the first hole detonates. This would reduce the chance of a cutoff. The 4-gr Primaline Primadet is steadily being replaced by other nonelectric systems.

Another alternative to obtain the delay pattern in Figure 3, and avoid the cutoff problem, would be to use the array of surface delays shown in the figure and an in-hole delay of an identical period in each blasthole. For instance, if a 75-ms delay is used in each hole, and the trunkline delays are each 9 ms, the delays in all of the holes except the two rear corner holes will be actuated before the first hole in the pattern fires, thus alleviating the cutoff problem. More complex patterns involving both surface and in-hole delays can be designed where desirable. An alternative method of obtaining in-hole delays with detonating cord is to use delay cast primers. These are cast primers with built-in nonelectric millisecond delays. They can be strung on detonating cord downlines of 25 gr or more and are particularly useful in obtaining multiple delayed deck charges with a single downline. It bears repeating that delay patterns involving both surface and in-hole delays can be somewhat complex and should be carefully laid out on paper before attempting to install them in the field.

GENERAL CONSIDERATIONS

Two of the primary advantages of detonating cord initiation systems are their ruggedness and their insensitivity. They function well under severe condi-

... large-diameter holes. They are not susceptible to electrical hazards, although lightning is always a hazard while loading any blast. Detonating cord is quite safe from accidental initiation until the initiating cap or delay connectors are attached. Available delay systems are extremely flexible and reasonably accurate.

There are several disadvantages that may be significant in certain situations. Systems employing only surface connectors for delays present the potential for cutoffs. Surface connectors also present the hazard of accidental initiation by impact. Detonating cord trunklines create a considerable amount of irritating, high-frequency airblast (noise). In populated areas the cord should be covered with 15 to 20 in of fine material or alternative, noiseless systems should be used. Detonating cord downlines present the problem of charge or stemming disruption. As discussed previously, this depends on the borehole diameter, the type of explosive, and core load of explosive in the cord. The means of checking the system is visual examination.

Vehicles should never pass over a loaded hole because the detonating cord lines may be damaged, resulting in a misfire or premature ignition. A premature ignition could result from driv-

DETALINE SYSTEM

Du Pont's Detaline System is a recently developed initiation system that is based on low-energy detonating cord. It functions similarly to conventional detonating cord systems except that the trunkline is low in noise, downlines will not disrupt the column of explosive, it will not initiate blasthole products, except dynamites, and all connections are made with connectors, rather than knots. The four components of the system are Detaline Cord, Detaline Starters, Detaline MS Surface Delays, and Detaline MS In-Hole Delays.

The Detaline Cord (Detacord) is a 2.4-gr/ft detonating cord whose appearance is similar to standard detonating cord. The cord is cut to lengths required for the blast pattern. This low-energy cord, while low in noise, has sufficient energy to disintegrate the cord upon detonation, which is advantageous where contamination of the blasted product must be avoided. Detacord will not propagate through a knot, which is why connectors are required. To splice a line or to make a nondelayed connection, a Detaline Starter is required. The body of the starter is shaped much like a clip-on detonating cord millisecond delay connector, except that the starter is shaped like an arrow to show the

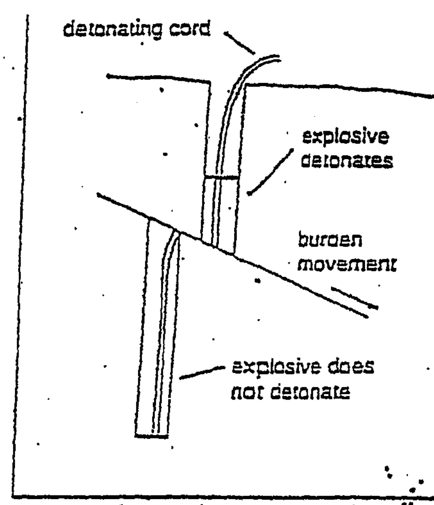


Figure 4—Misfire caused by cutoff from burden movement.

direction of detonation. To make a splice, the starter is connected to the two ends of the Detacord using the attached sawtooth pin, making sure that the arrow points in the direction of detonation. To make a connection, the donor trunkline is hooked into the tail of the starter and the acceptor trunkline, or downline, is hooked into the pointed end of the connector.

The Detaline System has provisions for both surface and in-hole delays. The surface delays, which come in periods of 9, 17, 30, 42, 60, and 100 ms, are shaped like the starter but are colored according to the delay. The surface delays are also unidirectional, with the arrow showing the direction of detonation. The surface delays can be hooked into a trunkline in which case their function is similar to that of a standard millisecond delay connector. They can

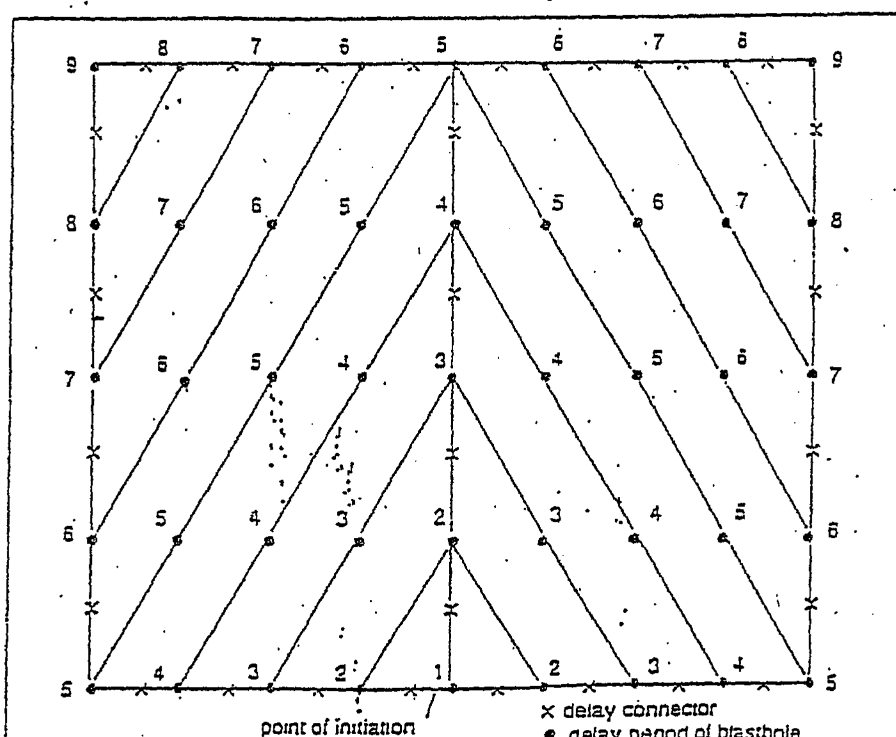


Figure 3—Typical blast pattern with surface delay connectors.

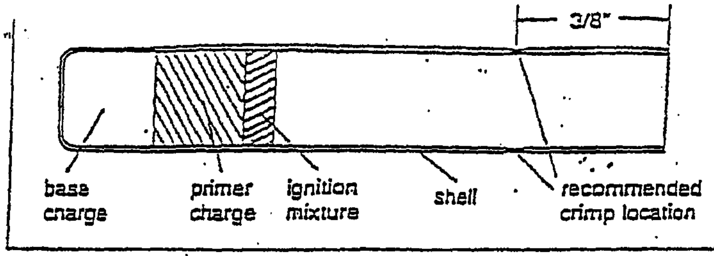


Figure 5—Blasting cap for use with safety fuse.

also be used as starters, connected between the trunkline and downline at the collar of the blasthole. In this situation the delay affects only the downline, and not the trunkline.

A Detaline MS In-Hole Delay resembles a standard blasting cap except for a special top closure for insertion of the Detacord. It functions similarly to a surface delay. Nineteen delay periods, ranging from 25 to 1,000 ms, are available. The delay is connected to the downline and is inserted into the primer.

Hookup of the Detaline System is similar to conventional detonating cord except that connectors are used rather than knots and right-angle connections are not necessary. When it is time to hook up, the Detaline trunkline is reeled out over the length of each row. Each downline is connected to the arrow end of a starter or a surface delay. The tail of each starter or surface delay is then connected into the trunkline. The open sides of the pattern are then connected in a manner similar to conventional detonating cord systems using Detacord and appropriate starters and surface delays. It is essential that all Detacord-to-Detacord connections be made with starters or surface delays rather than knots.

The Detaline System bears many similarities to conventional detonating cord systems. The system is checked out visually before firing. Combining surface and in-hole delays gives a practically unlimited number of delay combinations. It is convenient to build redundancy into the system. At firing time, the end of the trunkline tail extending from the shot is placed into the arrow end of a starter, and an electric or fuse blasting cap is inserted into the tail end of the starter and initiated.

The detonation energy of the 2.4-gr Detacord is adequate to disintegrate the trunkline. However, the resulting trunkline noise is quite low: typically about 13 dB lower than 25-gr detonating cord in field trials. A downline of Detacord will detonate most dynamites but will not detonate most water gels. A major advantage of a Detacord downline is that it will not disrupt a column of blasting agent. Detacord can be used as a total system or in conjunction with some standard detonating cord components. As with most newer systems, evolutionary changes may occur in the coming years. It is important that the manufacturer be consulted for recommended procedures for using Detacord. The manufacturer will also be able to recommend which variation of the system best suits a particular field situation.

CAP-AND-FUSE INITIATION

Cap and fuse is the oldest explosive initiation system; however, its use has dwindled steadily. Its primary remaining use is in small underground mines, although a few large mines still use it. Surface applications are limited to secondary blasting and the initiation of detonating cord rounds with a single cap.

COMPONENTS

The detonator used in a cap-and-fuse system is a small capsule that is open at one end (Fig. 5). The capsule contains a base charge and a heat-sensitive primer charge of explosive. The powder charge in the cap is initiated by a core of flammable powder in the safety fuse. Safety fuse has an appearance somewhat similar to detonating cord except that the surface of safety fuse is smoother and more waxy and the core load is black. The core load of detonating cord is white.

To assemble a cap and fuse, the fuse is carefully cut squarely and inserted into the cap until it abuts against the explosive charge in the cap. The fuse should never be twisted against the explosive charge in the cap. The cap is then crimped near the open end with an approved hand or bench crimper. The crimp should be no more than three-eighths of an inch from the open end of the cap.

FIELD APPLICATIONS

Currently, all safety fuse burns at the nominal rate of 40 sec/ft. Both dampness and high altitude will cause the fuse to burn more slowly. Fuse should be test burned periodically so that the blaster can keep a record of its actual burning rate. "Fast fuse" has been blamed for blasting accidents but the fact is that this rarely if ever occurs.

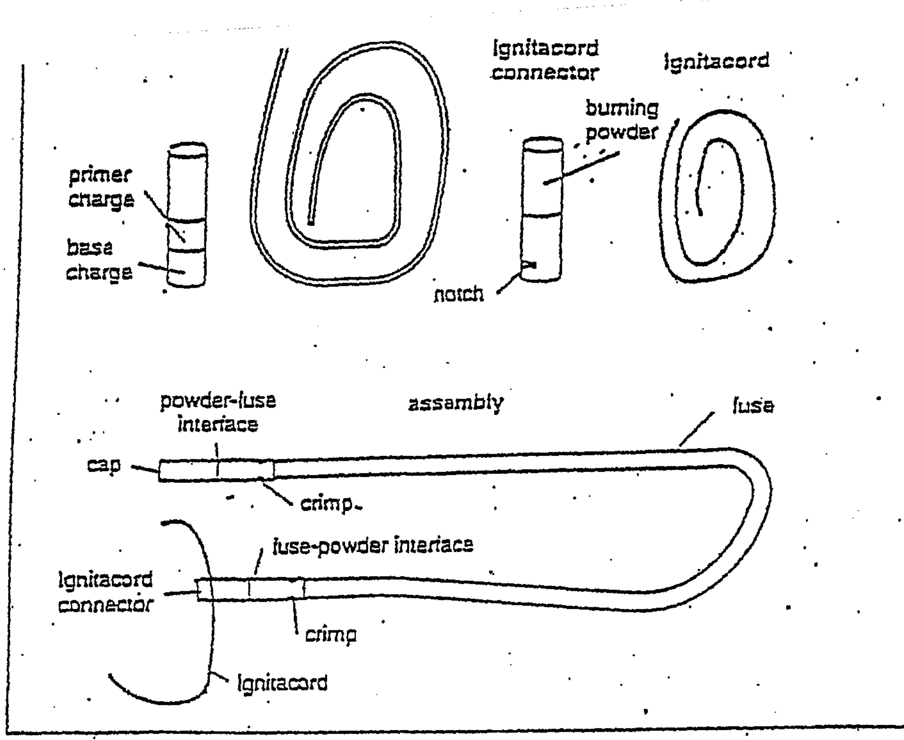


Figure 6—Cap, fuse, and Ignitacord assembly.

However, pressure on the fuse may increase its burning rate.

One of the most important considerations in the use of cap-and-fuse systems is the use of a positive, approved lighting mechanism. Matches, cigarette lighters, carbide lamps, or other open flames are not approved for lighting fuse. MSHA regulations specify hotwire lighters, lead spitters and Ignitacord as approved ignition systems. The safest, most controllable lighting method is Ignitacord. In South Africa, where safety fuse is most often sold as an assembly with an Ignitacord connector attached, the safety record with cap and fuse is much better than it is in the United States.

The Ignitacord connector fits over the end of the fuse and is crimped in a manner similar to the cap. Figure 6 shows a typical cap, fuse, and Ignitacord assembly. The cap is attached to the fuse with a bench or hand crimper, and never with the teeth or pliers. When crimping the cap, care should be taken not to crimp the zone containing the powder. The Ignitacord connector is crimped to the other end of the fuse with a hand crimper. The Ignitacord is inserted into the notch near the end of the connector and the notch is closed using the thumb.

To guard against water deterioration, it is a good idea to cut off a short length of fuse immediately before making cap-and-fuse assemblies. In deciding the length of fuse to cut for each primer, the lighting procedure must be considered. Ignitacord is strongly recommended because of its safety record.

When Ignitacord is used, each fuse must have a burning time of at least 2 min. To make sure of this time, the fuse must be calibrated periodically by test burning. The Ignitacord is attached to the Ignitacord connectors in the desired order of firing. If all the fuses are cut accurately to the same length, the desired order of firing will be achieved.

With Ignitacord, only one lighting is required before the shot firer returns to a safe location. Hotwire lighters and lead spitters require that each fuse be lit individually. The primary hazard of using safety fuse is the tendency of blasters to linger too long at the face, making sure that all the fuses are lit. To guard against this, MSHA regulations specify minimum burning times for fuses, depending on how many fuses one person lights. Keep in mind that two persons are required to be at the face while lighting fuse rounds.

If a person lights only one fuse, the minimum burning time is 2 min; for 2 to 5 fuses the minimum is 2-2/3 min; for 6 to 10 fuses the minimum is 3-1/3 min; [illegible] to 15 fuses the minimum is 5 min. One person may not light more than 15 fuses in a round. Although individual fuse lengths may be varied for delay purposes it is more dependable to cut all the fuses to the same length and use the sequence of lighting to determine the firing sequence.

To avoid misfires due to cutoff fuses, MSHA requires that the fuse in the last hole to fire is burning within the hole before the first hole fires. Kinks and sharp bends in the fuse should be avoided because they may cut off the powder train and cause a misfire. Many people who use cap and fuse do so because they feel that it is simpler to use than other initiation systems. However, proper use of cap and fuse requires as much or more skill and care as the other systems.

DELAYS

Cap and fuse is the only initiation system that offers neither flexibility nor accuracy in delays. Because of variations in lengths of fuse, burning rates, and time of lighting the individual holes will fire at erratic intervals at best, and out of sequence at worst. It is impossible to take advantage of the fragmentation benefits of millisecond delays when using the cap-and-fuse system.

GENERAL CONSIDERATIONS

There is no situation in which cap and fuse can be recommended as the best system to use. The system has two overpowering flaws—inaccurate timing and a poor safety record. The former results in generally poor fragmentation, a higher incidence of cutoffs, and less efficient pull of the round. All of these factors nullify the small cost advantage derived from the slightly lower cost of the system components. The poor safety record attained by cap and fuse is an even more serious drawback. It is the only system that requires the blaster to activate the blast from a hazardous location and then retreat to safety. The use of Ignitacord rather than individual fuse lighting alleviates this problem. A Bureau study (14) determined that the accident rate with cap and fuse is 17 times that of electric blasting, based on the number of units used. Too often, the person lighting the fuse is still at the face when the round detonates. The detonating the round makes security more difficult than with other systems.

Cap and fuse has the advantages of somewhat lower component costs, and protection from electrical hazards. If an operator decides to use the cap-and-[illegible] for lighting multiple holes is recommended because of its safety record.

>JEE<

(Cliff Ave., Cont'd from page 23)

property owner was given a letter informing them that construction was going to begin and that it would involve drilling and blasting. After this, we talked to each property owner and asked their permission to video tape the inside and outside of their property. Usually people were very cooperative. In a few instances, the property owner would only allow the outside of the structure to be video taped. In one instance, the owner would not allow any taping of the outside or inside. In these situations, we made note of the fact that they did not want us to tape and kept it on file.

For blast vibration records, we used an Instantel DS-477 seismograph. The seismograph was placed at the nearest structure to the blast. Along with the seismograph records, a blast log was kept for each shot. At the end of the day, the two were stapled together and kept in the job file for any future reference.

SEISMIC RESULTS

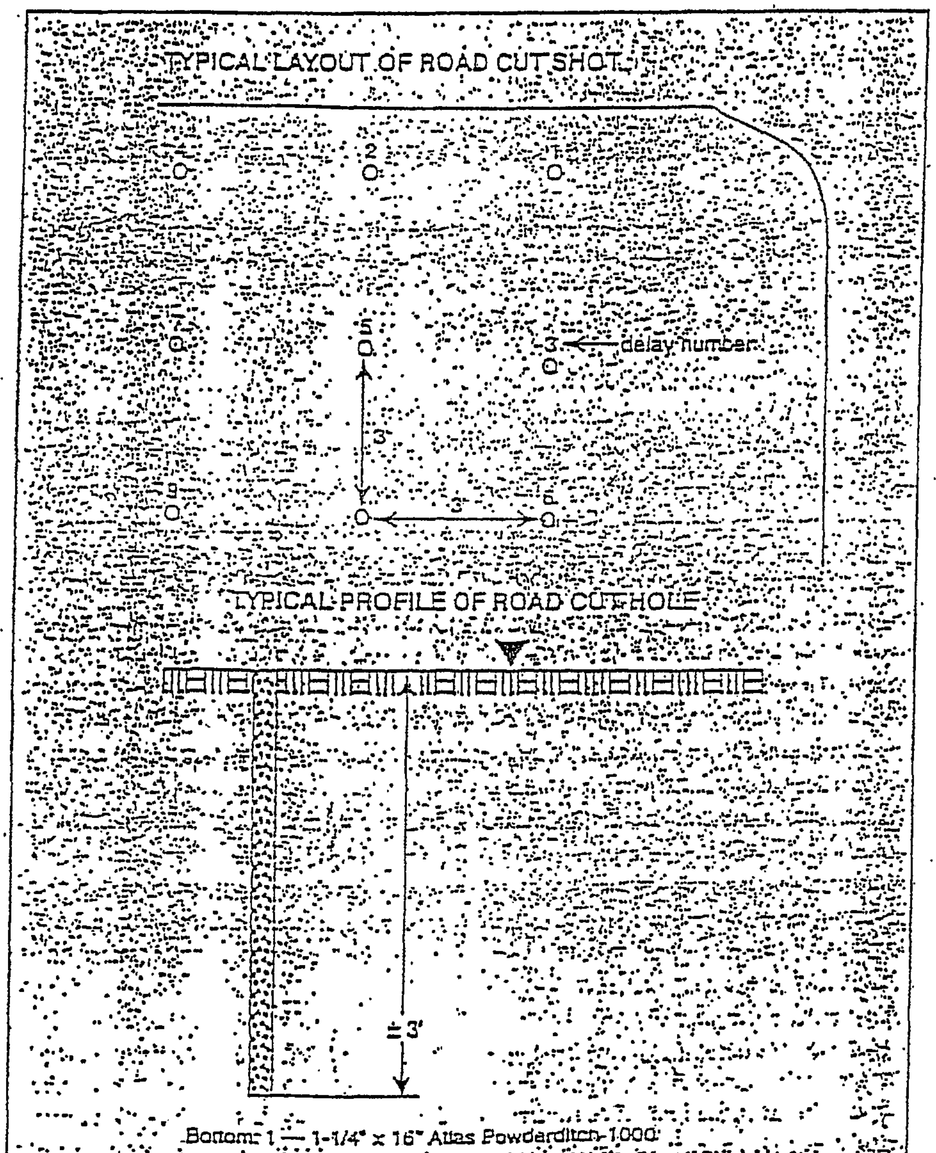
The seismic results in Table 2 give an idea of the "typical" readings obtained in each of the types of trench shots. These shots were some of the closest to existing structures and involve rock cuts of 3' to 7' in depth.

RESIDENTIAL RELATIONS

If there is one factor other than mother nature that can affect the progress of a job, it has to be the human factor. The residents located right on Cliff Avenue already knew that over half of their lawn would be gone, no access to their driveways for the better part of the summer, and all the noise and dust associated with a construction project would not be pleasant. Add drilling and blasting on top of this and you have the potential for a miserable project.

During the drilling and blasting portion of Cliff Avenue, Sweetman went out of its way to see that the concerns of the residents were being addressed. We maintained an open relationship with the residents involved with the drilling and blasting on their property. If people wanted to see the "powder" we made sure they saw it and explained how we used it. If they asked about "that blue box" (the seismograph), we explained to them that it told us how much vibration was being caused by the blasting. The more the people asked us about the blasting portion of the project, the more at ease they seemed. We had to listen to our share of "When I was in the military" stories too, but the residents enjoyed telling us about them and we were happy to listen.

Since all of our shots were matted, the most common response of a first time "shot watcher" was "Is that all?!". It was the biggest compliment we could receive.



CONCLUSION

The blasting techniques used on the Cliff Avenue Reconstruction Project were designed to remove approximately 5,200 yd³ of pink Sioux Quartzite for the construction of a five-lane highway and all related underground utilities. Of the 5,200 yd³ of rock removed, 1,000 yd³ came from a shallow road cut and the remaining 4,200 yd³ was removed from the storm sewer, sanitary sewer, and water main trenches.

With the positive results of this drilling and blasting project, the public is slowly shedding the negative attitude associated with explosives and realizing what a delicate science the explosives field really is. >JEE<

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Back to Basics: Electric Initiation
Components Part 1

BACK TO THE BASICS
ELECTRIC INITIATION COMPONENTS
Part 1

by
Larry Schneider

Electric blasting caps were introduced in the United States in the late nineteenth century and the electric delay caps were invented around the turn of the century. And during the past one hundred years, electric initiation has been a proven method for initiating explosive charges in the mining and construction industry While the earliest electric detonators were constructed with cotton-braided insulation on the leg wires and may have had delay times of uncertain accuracy modern electric detonators are coated with waterproof plastic insulation capable of withstanding 3000 volts. Furthermore, in recent years, the accuracy of the delay times built into current electric detonators has improved dramatically

The chief advantage to using electric initiation systems is that the electric circuit including the detonators can be checked prior to firing. Such a test can detect not only the continuity of the circuit, but by evaluating the resistance of the circuit, the blaster may find potential problems before detonation A minor advantage may be the fact that the copper wire used in electric blasting is a material which can be recovered. However, it is important to note that if the blasting crew does collect this used wire, that it be sold to a recycling facility and not reused. Connecting wire should never be reused on a blast in order to avoid possible problems in the event that the wire has sus tamed some damage that is not readily apparent.

Other advantages of electric blasting, which it shares with the nonelectric systems are:

1) The blast can be detonated remotely from a safe distance and a safe location.

2) The blaster controls the precise moment of detonation.

3) A variety of long and short interval delays are readily available.

The chief disadvantage to electric blasting is that the electric detonators are susceptible to premature detonation caused by lightning, radio transmissions, static electricity or any other source of extraneous electric energy

The necessary components of an electric firing system include the following:

1) Detonators - Electric detonators are designed to fire when sufficient current is applied to them, and they must detonate with sufficient strength to cause any high explosives with which they are in contact to also initiate. The detonators may be instantaneous, which means they fire immediately upon application of the current. Or they may be delay detonators which means they fire at a preset time after the current has been applied.

2) Power Source - The source of the firing current for an electric blasting circuit is usually a capacitor discharge (CD) blasting machine. However, a few blasters may still use the old style push down, or twist type hand generator type blasting machine. Certain operations such as underground quarries may use power lines to fire blasts.

3) **Wiring** - The wiring used in electric blasting include the leg wires of the detonator, any connecting wire used to hook the leg wires of individual caps or series of caps together, and the "lead line" or "firing line," which connects the power source to the blasting circuit.

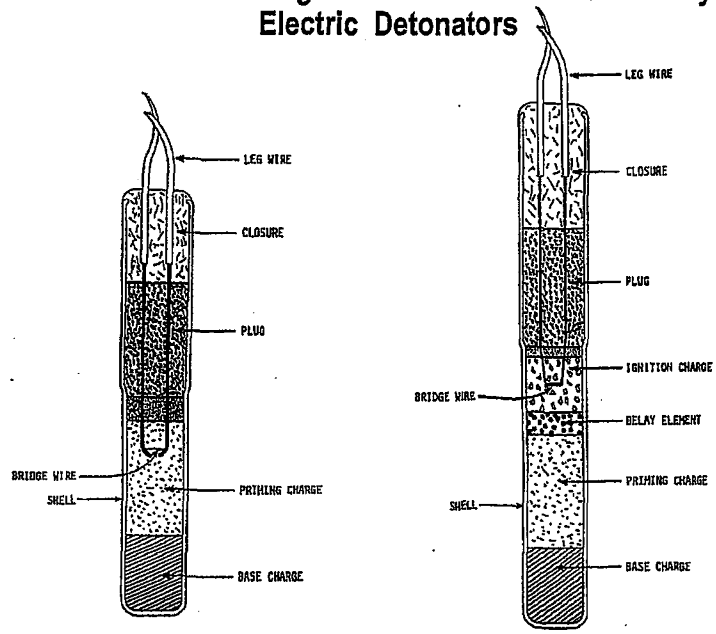
4) Test **Equipment** - Blasting galvanometer, blasting multimeters, or any other test device built specifically to test electric blasting circuits for continuity or to measure their resistance, and other electrical characteristics.

ELECTRIC DETONATORS

Electric Detonators are available from their manufactures in a variety of trade names or designations. These designations may indicate that the detonators are either "short interval" delay detonators or "long interval" delay detonators. The "short interval" detonators consist of detonators whose firing times are measured in milliseconds (1/1000 of a second). The so called "long interval" detonators have firing times which are separated by times on the order of 0.5 or 1.0 second. Both types are available in "series" of detonators with similar electrical firing characteristics but with different firing times. These series may consist of 10, 20 or 30 or more detonators with different firing times arranged in order of their nominal firing time. These detonators are identified by a number which is referred to as the delay number. Both delay number and firing time, as well as the manufacturer and brand name, can be found on the identification tag attached to the leg wires.

The cut-away diagram illustrates the construction of a generic instantaneous and delay electric blasting detonators. While the actual elements of each type of detonator may differ slightly in shape and composition from different manufactures, the basic elements necessary to the function of the detonator are similar.

Cross-Section Diagram of Instantaneous & Delay Electric Detonators



When sufficient electric current is applied to the detonator through the leg wire, the electric energy causes the bridge wire to heat up in a manner similar to the filament of a light bulb. (In some electric detonators, the bridge wire is replace by an electric match assembly which performs the same function as the bridge wire, that is, converts the electric signal to a burn) Since the bridge wire is in contact with a heat sensitive chemical called the ignition compound, the heat from the bridge wire causes this compound to begin to burn. In an instantaneous detonator, the burning of this ignition compound immediately causes the detonation of a primer charge which in turn sets off the base charge.

In delay detonator, there is a delay element between the ignition compound and the primer charge which slows the progression of the burning inside the cap for a pre-determined length of time. This time corresponds to the delay time of the detonator. Provided that neither an excessive, nor insufficient, electric current is applied to the detonator, the delay time is unaffected by the firing current. All detonators in a firing circuit receive the electric current at the same time; the time interval between the application of the current to the bridge wire and the detonation of the base charge is determined by the composition and the amount of the delay element.

Other features of an electric detonator are the metal shell which encases the explosive compounds, the sealing plug where the leg wires enter the shell, the leg wires, and the shunt attached to the leg wires. The metal shell of the detonator is made of aluminum in most detonators, and the leg wires are normally copper. For some applications, where contaminants are removed from the blasted materials by means of magnetic separation, the leg wires are made of iron. Iron leg wires have a much greater electric resistance than the copper ones and will limit the number of detonators in a single series or a circuit, Both types of leg wires are coated with plastic insulation. At the opposite end of the leg wires from the detonator, a metal shunt will be attached to the bare ends of the leg wires. This shunt is either metal foil or other conducting material, which froms a short circuit across the bridgewire providing some protection from stray currents. Due to the added safety the shunt provides, it should never be removed until the time the detonator is wired into the blasting circuit.

The sealing plug is tightly crimped into the open end of the detonator during manufachlre and forms a waterproof closure. It also provides a firm attachment for the leg wires where they enter the shell of the detonator.

POWER SOURCE

In order to initiate a blasting circuit, there must be a reliable source of sufficient electrical energy which can be delivered in a short period of time. An older style of blasting machine, which the general public commonly associates with blasting, is the "rack bar of push down" generator. These machines are operated manually; when the handle is pushed down, a series of gears spins a rotor inside the generator assembly producing a voltage. When the handle reaches the end of its travel, it closes a switch which delivers the current produced to the output terminals of the machine. Such a generator type blasting machine has a limited capacity and its output can vary depending upon the condition of the machine and the strength of the operator. For these reasons, it has been replaced at most blasting operation with capacitor discharge (CD) machines.

The CD blasting machines operate by using batteries and an electronic circuit to charge a series of capacitors. After the capacitors are fully charged, a firing switch discharges this energy through the blasting circuit connected to it. These CD blasting machines are available in a wide variety of designs and capacities. Some of the newer machines are physically very small yet capable of firing over 100 electric detonators in a series. Some of the larger machines can easily fire up to **1000** caps in a series parallel arrangement. When selecting or using a CD blasting machine, the blaster must be sure that the machine he is using is capable of supplying sufficient energy to all the detonators in the circuit so they reliably fire. The data, usually in the form of graphs or tables, required to evaluate the capacity of each CD machine is available from their manufacturer.

A special class of CD blasting machines is the sequential timing blasting machine which consists of a number of separate capacitor circuits and output terminals each capable of firing a series of electric detonators. These separate firing circuits discharge their energy at predetermined time intervals, and thus provide an alternate method of delaying the initiation of electric detonators. When used in combination with electric delay detonators, sequential blasting machines provide a method of producing up to several hundred separate delay intervals in a single blast.

In some operations, such as in certain underground mines, firing the blasting circuits is done by means of a power line. Whenever such power line blasting is used, special care must be taken in designing the circuit, the switches, and the available voltage and current. Such power line firing requires added precautions to ensure that there is an adequate amount of energy for the detonators, and at the same time, ensure that there is not an excessive amount of electrical energy applied which could cause arcing, hangfires, or misfires. A lightning gap, which is a physical break in the circuit of sufficient size to prevent lightning from arcing across it, must be used in any power line system. The overall circuit must be evaluated by an experienced electrician, knowledgeable about the safety standards required for electric blasting, and the power line should be used solely for blasting.

Wire Size and Resistance Chart

Gauge Size	Wire Diameter (inches)	Ohms per 1000 feet of copper wire at 20" C.
10	.101	0.99
12	.080	1.59
14	.064	2.62
16	.050	4.02
18	.040	6.39
20	.032	10.1
22	.025	76.2

WIRING

The leg wires are the wires which extend from the detonator and come in a variety of lengths from six feet to several hundred feet long. Obviously, the deeper the borehole is drilled and the larger the burden and spacing are, the longer the leg wires of the detonator must be. The electrical resistance of the detonator is primarily determined by the length of the leg wires. For example, detonators with copper leg wires 20 feet long may have an electrical resistance of 1.66 ohms; however, the same type detonator with 60 foot leg wires will have a resistance of 2.18 ohms. The resistance of the detonators used is a vital piece of information required to design the blasting circuit.

Another type of wire used in blasting circuits is the connecting wire, which is used to extend the length of the leg wires on the surface, or to connect one series of detonators to another. Connecting wire should be made of single strand, solid copper wire of sufficient diameter to minimize the resistance of the circuit. Such con-

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necting wire should be between #18 and #22 gauge size depending on the current required and the output of the power source. Wire diameter is measured in terms of gauge size with the smaller gauge number indicating larger wire diameters. As can be seen from the table, gauge size #18 has a larger diameter than #22,

be long enough to allow the blaster to fire the shot from a safe distance and at a location providing sufficient cover.

Lead should be at least #16 or #14 gauge size, conductors smaller than this are not recommended. Larger conductors, such as #12 gauge may be required in instances where very long lead lines are required. Stranded wire is never recommended for use on a blast site, since over time the strands may be broken by falling rocks or rough handling, which would effectively reduce the current carrying capacity of the wire.

TEST EQUIPMENT

As mentioned previously one of the chief advantages of electric blasting is the ability to check the circuit's resistance and continuity However, to make use of this aspect of the electric initiation, the blaster must have the proper test equipment, that is, a blasting galvanometer, or blasting multimeter. When measuring the resistance of a blasting circuit, these instruments operate by sending a minute amount of current through the circuit, therefore, it is critically important that only equipment specifically designed for use in blasting circuits be used. The output of the blasting galvanometer or multimeter is limited to prevent any possibility of firing the detonators. For this reason it is also important that; no one tamper with the test equipment, that only authorized agents repair this equipment, and when replacing batteries in the equipment, use only identical replacements.

The blasting galvanometer, which is more accurately called a blasting ohmmeter, measures only the resistance of the circuit it is testing. A blasting multimeter can not only measure the resistance of a circuit, but also has the capability to measure stray currents, test the output voltage of the blasting machine, check for current leakage, make several other electrical tests. *>JEE<*

Engineering
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Back to Basics:
Electric Initiation Part 2

BACK TO THE BASICS
ELECTRIC INITIATION
Part 2
CURRENT & RESISTANCE CALCULATIONS

by
Larry Schneider

FUNDAMENTAL ELECTRICAL QUANTITIES

The proper application of an electric initiation system requires that each and every detonator in the blasting circuit receives an adequate amount of electrical energy so that it will reliably fire. The power source, such as a blasting machine, provides the electrical energy; lead line, connecting wires, and leg wires provide a continuous path to transmit the energy and the electric detonators convert this electric energy into an explosive initiation sequence described in the last article.

To ensure that these components work properly requires planning the blasting circuit based upon an evaluation of the capacity of the power source, the number and type of detonators to be used in a blast, the amount and size of wire to be used. Any technical discussion of electric initiation must necessarily include some understanding of the fundamental principles of basic electricity Specifically this means a knowledge of electrical quantities such as; voltage, current, resistance, and energy as well as the basic types of circuit configuration, series, parallel, and series-parallel.

Electric current is the actual time rate of flow of electric charges through a conduct and is measured in units of amperes (or amps). Voltage, which is measured in units of volts, is the difference of electric potential measured between two points. It can be thought of as a type of electric pressure causing current to flow between points of different potential in a circuit. Resistance is oppo sition to the flow of electrical charges through any conductor or component, and is measured in units of ohms (Ω is the symbol for ohms). Electrical energy when used in the context of energy delivered to a component such as an electric detonator in a blasting circuit, is measured in terms of joules.

The electrical quantities of voltage, current, and resistance in a circuit or portion of a circuit are related by one of the most fundamental equations of electricity Ohm's Law This law states that the amount of current flowing in a circuit is equal to the voltage applied divided by the total resistance of the circuit.

$$I = \frac{V}{R}$$

In Ohm's Law, I is the symbol for current measured in amps, V is voltage, and R is the resistance.

If the resistance of a circuit and the voltage of a power supply are known, the amount of current that will flow can be predicted by the use of this equation. For example, if a 12 volt battery is connected to a lightbulb with a resistance of 50 ohms, the current which will flow through the light bulb is equal to the voltage, 12 volts, divided by the resistance, 50 Ohms or 12/50 amps, which equals 0.24 amps.

However, with blasting circuits, Ohms law is applicable only in very limited instances, such as when an alternating current (AC) power line is used to fire the detonators. In usual blasting situations, where a capacitor-discharge (CD) blasting machine is used to initiate the blasting circuits, **Ohm's** law cannot be used to calculate current delivered to the circuit. All CD blasting machines apply a voltage to the blasting circuit which decreases exponentially from its maximum value to zero within a few milliseconds. Since this applied voltage is not constant and decreases in a non-linear manner, Ohms law is neither appropriate nor accurate in this case. There is, however, a mathematical method used to calculate an "effective current" from a CD blasting machine if the total capacitance of the machine and the voltage is known. This method is described in detail in reference books, such as ***Explosives and Rock Blasting,*** published by the Atlas Powder Company in 198%

Regardless of which method is used, before the blaster can find the current and energy supplied to the detonator, he must first determine the total resistance of the firing circuit. As mentioned earlier, this resistance is the opposition to the flow of current, and from that description, it follows that the larger the resistance of a circuit, the less current will flow in the circuit if voltage remains constant.

The first step in determining the resistance of a blasting circuit is to calculate the resistance of the detonators in the circuit. The resistance of detonators in a blasting circuit is a function of the resistance of the individual detonators and the type of circuit into which they are wired.

The series circuit is the simplest, which provides a single path for current to flow It is one closed loop connecting the power source to all the components (in this case, detonators) in the circuit. Several examples of series circuits are shown in figure 1.

In series circuits, all detonators receive the same amount of current, which reduces the possibility of partial misfires that can occur when some detonators receive sufficient current to fire and others do not. A single series is also very easy to check for con-

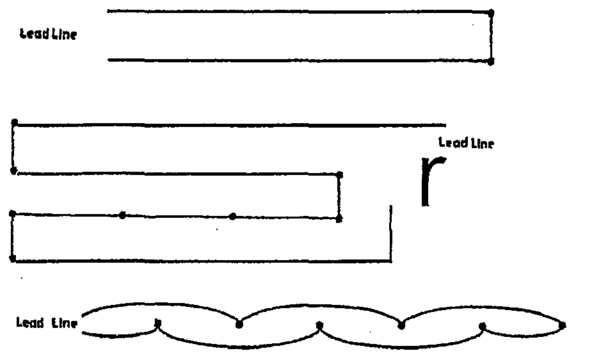

Figure 1

tinuity and to measure the resistance with a blaster's ohmmeter. However, one disadvantage to a series circuit is the fact that the resistance of the circuit increases with the number of detonators wired into the series. This limits the number of detonators that can be fired, based upon the output of the blasting machine.

In a series circuit, the total resistance of the circuit is the sum of all resistances in that series and the equation for calculating that resistance is written as follows:

$$R_{total} = R_1 + R_2 + R_3 + \ldots R_n$$

R_{total} is the **total resistance of the series circuit, R1, R2 etc. is the** resistance **of the individual detonator in the circuit. and n is the number of caps in the circuit.**

The first sketch in figure 1 shows a blast circuit with ten boreholes, each with a single electric cap. Therefore, the total resistance would equal to the sum of the resistances of the ten individual detonators. A typical electric detonator will have a resistance between 1 ohm and 3 ohms. The factors which determine the resistance of individual detonators are the length of the legwires, the gauge or thickness of the legwires, and whether the wires are copper or iron. From the following table we can generalize and say that the longer the legwires, the higher the resistance of the cap; also it is obvious from the table that caps with iron legwires have greater resistance than caps with copper legwires.

Table A is intended as an example only; the resistance of detonators from various manufacturers will differ. Check with the manufacturer to obtain a chart or table of the resistances for each particular brand of detonator.

If we assume the detonators in our example have legwires which are 40 ft. long and a resistance of 2.3 Ω, the total resistance of the five detonators in series would be:

R_{total} = 2. 3+2. 3+2. 3+2. 3+2. 3+2. 3+2. 3+2. 3+2. 3+2. 3=23. 5Ω

Since in this example, the resistance of all detonators are identical, the total resistance could also be found by multiplying the number of detonators by the resistance of each one. That is, ten times 2.3 ohms, which equals 23.5 Ohms.

A second basic type of electrical circuit is the pure parallel circuit. While this circuit is occasionally used in blasting operations, it has serious disadvantages that limit its usefulness. A parallel circuit is any circuit which provides two or more alternate paths for the current to flow Several simple schematic drawings of parallel circuits are shown in figure 2.

In most cases, parallel circuits are a very poor method to wire a blast circuit for several reasons. Such circuits are very difficult to test for continuity or to measure its total resistance of the circuit. If a blasting ohmmeter is connected to a parallel circuit to measure its total resistance, the meter will show a very small resistance. In fact with a typical blasting ohmmeter, the pointer needle will indicate a resistance near zero, which makes such a circuit indistinguishable from a short circuit. Due to the fact that this total resistance is so small, it is also impossible to tell by measuring the resistance of the circuit if one or more of the detonators have been left out of the circuit. Another potential hazard is that a break in one branch of a parallel circuit will not prevent current from flowing in the other branches. This means that this method of firing is more susceptible to partial misfires than a series circuit.

To calculate the resistance of a parallel circuit, the following equation is used:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

R_{total} is the resistance of the parallel circuit and R1, R2, are the resistances of individual detonators.

Using the same detonators in the previous example, but this time assume there are five connected in parallel.

$$\frac{1}{R_{total}} = \frac{1}{2.3} + \frac{1}{2.3} + \frac{1}{2.3} + \frac{1}{2.3} + \frac{1}{2.3} = \frac{5}{2.3}$$

TABLE A Nominal Resistance of EB Caps
Resistance in Ohms per cap

Legwire Length	Copper Legwires	Iron Legwires
12 "	1.8 "	4.3 "
16 "	1.9 "	5.3 "
20 "	2.1 "	6.3 "
24 "	2.3 "	7.3 "
28 "	2.4 "	8.3 "
30 "	2.1 "	8.8 "
40 "	2.3 "	11.3 "
50 "	2.6 "	13.8 "

$$R_{total} = \frac{2.3}{5} = 0.46\Omega$$

From the above calculation, it can be seen that a circuit with several detonators wired in parallel to each other will have total resistance less than the resistance of an individual detonator, While this means that there is less opposition to current, flow the configuration of the circuit requires that a greater current flows from the power source in order to supply the detonator in each path with a sufficient amount.

The third type of circuit, and the one in which such resistance calculations are most often necessary and practical is the combination series-parallel circuit. These circuits are used when the number of detonators to be fired exceeds the capacity of the blasting machine for a single series. The shot is then broken down into two or more series, and these [illegible] with each other. A simple example of a series parallel blasting circuit is shown in the first diagram of figure 3, where 48 detonators wired into 6 series of 8 caps each. The 6 series are connected in parallel with each other.

To find the total resistance of this circuit, the blaster must first calculate the resistance of each series. If we again assume that the detonators in this circuit have a resistance of 2.3 ohms each, the resistance of the series of eight detonators is:

$$R_{total} = 2.3+2.3+2.3+2.3+2.3+2.3+2.3+2.3=18.4\Omega$$

Since these six series are wired in parallel with each other, the total resistance of the circuit will be found using the equation for resistance in parallel:

$$\frac{1}{R_{total}} = \frac{1}{18.4} + \frac{1}{18.4} + \frac{1}{18.4} + \frac{1}{18.4} + \frac{1}{18.4} + \frac{1}{18.4}$$

$$\frac{1}{R_{total}} = \frac{6}{18.4}$$

$$R_{total} = \frac{18.4}{6} = 3.06\Omega$$

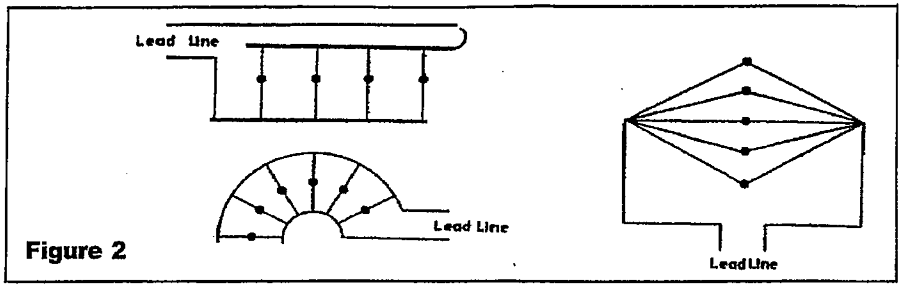

Figure 2

From this calculation, it again can be seen that the total resistance of the circuit, 3.06 ohms, is less than the resistance of the individual series, 18.4 ohms. Since the total resistance is reduced, the amount of current flowing through the circuit is increased. However, since there are four separate paths for the current to flow the minimum current required is four times that of a single series.

One critical fact that must be kept in mind when blasting with parallel or series-parallel circuits is that all parallel branches of the cir- [illegible] resistance in order that the current delivered to the circuit is divided evenly through the parallel branches. If there is a significant difference in the resistances from one parallel branch to another, the current will flow more readily through the branch with the lower resistance. Therefore, a parallel branch with a resistance greater than the other branches may receive less current, which may be below the level required to reliably fire the shot.

CALCULATING RESISTANCE OF WIRING

The preceding calculations consider only the resistance of the detonators and their legwires. In an actual blasting circuit, the lead line and any connecting wire used may also contribute resistance to the circuit. While in most cases these items will add only a few ohms to the overall resistance, in some blasting circuits this small additional resistance may be critical.

In pure parallel circuits, the resistance of the wires may become significant, and actually [illegible] caps. In most series circuits, the contribution of the lead line resistance and the connecting wire resistance is very small compared to the resistance of the caps. In very large series parallel circuits the resistance of the connecting wire and the firing line becomes noticeable. In fact, the greater the number of parallel branches contained in a circuit, the more significant the resistance of the wires become.

When calculating the resis-

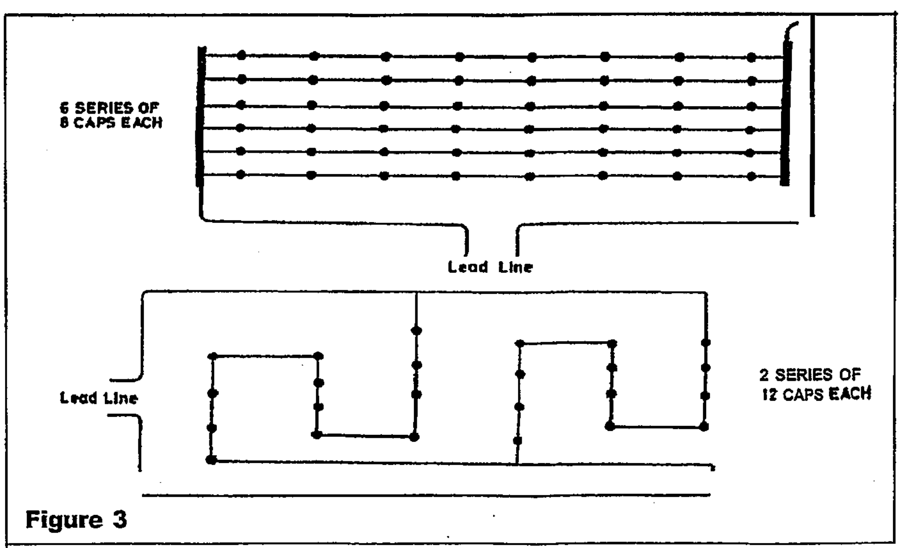

Figure 3

TABLE B
Resistance of Copper and Iron Wire

Gauge	Diameter in Inches	Ohms/1000 ft Copper	Ohms/1000 ft Iron
6	0.1620	0.39	1.4
8	0.1285	0.63	3.7
10	0.1019	1.00	6.1
12	0.0808	1.60	9.8
14	0.0641	2.53	15.6
16	0.0508	4.02	24.8
18	0.0403	6.38	39.5
20	0.0320	10.15	62.7
22	0.0254	16.14	100
24	0.0201	25.67	159

tance of any wire, it will be determined by the following things:

(1) Length - the longer a wire, the higher the resistance

(2) **Thickness or Gauge** - the thicker the conductor, the less resistance

(3) Type of metal - copper has less resistance than iron.

Wire thickness or "cross - sectional area" is designated by a gauge number which can range from 0 to 24. These numbers are arranged so that the smaller the gauge number, the thicker the wires. As an example, #10 gauge wire has a larger cross - sectional area (thicker) than #12 gauge wire.

A lead line should be #12 gauge or #14, with the #12 gauge preferred since it has less resistance. Connecting wire is normally #18 or #20 gauge copper wire.

Table B gives the resistance per 1,000 feet of various gauges of wire.

The formula for calculating resistance for any type of wire is simply the length of wire divided by 1000 times the resistance per 1000 feet. As an example, to find the resistance of 600 feet of 20 gauge copper connecting wire, the calculation is as follows:

Resistance of Wire =

$$\frac{\text{Length (ft)}}{1000\text{ ft}} \times \text{Resistance from Table}$$

Resistance of Wire =

$$\frac{600\text{ ft}}{1000\text{ ft}} \times 10.15\text{ Ohms} = 6.09\text{ Ohms}$$

It is possible that a lead line or firing line may be a duplex cable; that is, it is made up of two wires inside an insulating covering. This means that a lead line 250 feet long actually has two 250 foot conductors inside it, and the total length of the current-carrying wire is 500 feet.

An example of 750 ft duplex lead line of 12 gauge wire is found to have a resistance of:

Actual length of duplex conductor =
2 X 750 = 1500 ft.

$$R = \frac{1500\text{ ft.}}{1000\text{ ft}} \times 1.60\text{ Ohms} = 2.4\text{ Ohms}$$

To compute the total resistance of the blast circuit, the resistance of the firing line and the resistance of any connecting wire used, is added to the resistance of the cap circuit. This total resistance is what is measured with a blaster's ohmmeter at the end of the lead line. It is this resistance that will determine whether of not sufficient current will be able to flow through the blasting circuit. Most generator type or CD type machines will have technical data readily available listing how much electric current or energy they will supply through a certain resistance. Each machine will be different, and the blaster needs to be aware of this information in order to prevent misfires from inadequate current distribution.

Once the total resistance of a circuit is found, the current flowing through that circuit can be found. Unless the blasting circuit is fired from a specially designed power line where Ohm's Law would be applicable, the blaster must refer to a chart or table of firing currents that should accompany the CD blasting machine.

Current found in either of these ways can then be compared to the minimum current necessary to fire a cap circuit. The current available must be greater than the minimum firing requirement, to eliminate the possibility of misfire due to lack of available electrical energy If the available current is calculated to be less than that prescribed by the table of minimum current requirements, there is a risk of misfired charges when the shot is detonated.

To find the minimum, refer to a table such as Table 4 below

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TABLE 4
Minimum Firing Current For Electric Detonators,
from Atlas Powder Company's *Explosives and Rock Blasting,* ©1987

CIRCUIT	DC POWER SOURCE	AC POWER SOURCE
Single Detonator	0.5 amps/detonator	0.5 amps/detonator
Single Series	1.5 amp	2.0 amps
Parallel	Minimum of 1.0 amps/detonator Maximum of 10 amps/detonator	Minimum of 1.0 amps/detonator Maximum of 10 amps/detonator
Series- Parallel	1.5 amps per series	2.0 amps per series

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Back to Basics:
Electric Initiation Part 3

BACK TO THE BASICS
ELECTRIC INITIATION
Part 3
PLANNING & TESTING CIRCUITS

by
Larry Schneider

USING A BLASTING OHMMETER OR GALVANOMETER

Regardless of whether a blaster fires one electric detonator per shot or a thousand, one of the most important tools he will use is a blasting galvanometer. This instrument is sometimes more accurately referred to as a blasting ohmmeter, since it measures resistance of a blasting circuit or detonator in ohms. In this article, the term blasting ohmmeter will be used to refer to any of these test instruments designed to be used in circuits containing detonators.

When blasting electrically, it is good practice to check both the resistance of individual detonators, as well as the complete circuit with a blasting ohmmeter. In some areas, regulations specify when an ohmmeter must be used. Most regulatory and safety standards also warn that only a blasting galvanometer, ohmmeter, or multimeter designed specifically for measuring blasting circuits and designated as such, be used. Failure to follow this rule by using an ordinary electrician's ohmmeter or volt-ohmmeter can result in premature detonation, and subsequent injury or death.

An ordinary ohmmeter is inherently dangerous in a circuit containing detonators due to the way it operates. When any ohmmeter is connected to a closed circuit, current from an internal battery in the instrument flows through the circuit being tested. With an ordinary ohmmeter, the amount of current that the instrument introduces into the circuit can be sufficient to initiate any electric detonator in the circuit.

The ohmmeters and multimeters designed specifically for blasting circuits limit the amount of current that can flow from the meter into the circuit. In fact, the original type of blasting ohmmeter was powered by silver chloride cells, which are incapable of producing enough current to fire a typical electric detonator. Other approved blasting ohmmeters, or multimeters, which are powered by more common and readily available batteries, restrict current with limiting resistors inside the instrument.

Whatever type of blasting ohmmeter is used, it is critical that when the internal batteries are changed, they are replaced with identical batteries, or with batteries specified by the manufacturer of that precise instrument. Ohmmeters can be checked prior to every use by touching a conductor, such as a screwdriver, across both terminals. When this is done, the needle should read full scale deflection or zero ohms. If it does not, and cannot be made to read zero by means of an adjusting screw, the batteries are likely to be low, and need replacement.

In very cold weather, an ohmmeter may not give accurate readings due to the effect of the temperature on the battery In these situations, the ohmmeter should be kept reasonably warm before use. Water or extreme moisture may also damage this instrument, or affect its readings.

Ohmmeters are sometimes used by a blaster to merely check the continuity of individual detonators before the primer is made, or the continuity of the entire blasting circuit. However, the real value of a blasting ohmmeter is that it enables the blaster to measure the actual resistance of a blasting circuit, and use this information to evaluate his wiring of the blasting circuit.

After the resistance of a circuit has been measured by the ohmmeter in the field, it can be compared to the calculated resistance of a circuit. Any discrepancy found between these two values can indicate problems in the firing circuit such as follows:

(A)If the measured resistance is significantly HIGHER than the calculated resistance, it may be a sign of dirty or loose connections, damaged connecting wire or lead wires, or that one or more series is open in a series parallel connection.

(B)If the measured resistance is significantly LOWER than the calculated resistance, it may be due to a partial short circuit or the fact that some detonators were left out of the circuit when wiring it.

(C)If the ohmmeter needle does not move, indicating infinite resistance, there is a break in the circuit and current cannot flow

(D)If the ohmmeter needle deflects full scale, reading close to zero ohms, that indicates that there is a short circuit, most likely in the lead line.

Any of these problems can result in a complete or partial misfire. If detected by use of the ohmmeter, corrective measures must be taken before attempting to fire the blast.

As mentioned earlier, other instruments called blaster's multimeters are also designed for use with blasting circuits. These instruments are capable of measuring voltage and current as well as resistance. Such multimeters are useful in checking (1) the output of blasting machines, (2) for stray currents, and (3) for current leakage.

A blaster should occasionally check his lead line for continuity and measure its resistance with his blaster's ohmmeter, or multimeter. This is done by measuring the lead line's resistance in two ways; once with one end of the lead line shorted, and then again with that end open. The lead line should be unrolled from the spool and stretched out as if it were wired into a blasting circuit before testing.

When one end of the lead line is shunted, an ohmmeter at the opposite end of the lead line should measure only a few ohms. A resistance reading of zero ohms, or one higher than expected, indicates that there is a problem with the lead wire. After completing this test, one end of the lead line should be left open and the blasting ohmmeter attached to the opposite end. In this case, the ohmmeter needle should not deflect. Any reading of resistance in this case indicates a short circuit in the lead line.

DETERMINING HOW MANY SERIES TO USE IN A CIRCUIT

A previous article of this series explained the necessity of providing an adequate amount of current and electrical energy to every detonator in the blasting circuit. A blast with a large number of electric detonators must be wired in a series-parallel circuit, unless the blasting machine has an unusually large capacity and can fire all the detonators in a single series. A typical condenser-discharge blasting machine normally can provide enough current and energy to reliably fire only 40 to 50 detonators in a single series.

When a blast exceeds that number of detonators, the blaster must decide how many series to use. For example, consider a blast that contains 240 boreholes, each loaded with a single electric detonator. An initiation circuit could be wired containing 3 series of 80 caps each, 4 series of 60 caps each, 6 series of 40 caps each, 8 series of 30 caps each, and so forth. The greater the number of series used, the less the total resistance of the circuit will be. However, the greater the number of series used, the larger the current must be since it must be divided among the series. The question remains, how many series would be the best way to wire the circuit? That is, which configuration will provide the maximum current and energy to every detonator?

The blaster could go through all the resistance and current calculation for every possible series-parallel combination, but that would be time-consuming and unnecessary There is a general rule that the current to the detonator is maximized when the resistance of the detonator circuit is approximately equal to the resistance of the connecting wire and the lead line. A mathematical equation, used to calculate the number of series, S, based upon a physics theory known as the Maximum Power Transfer, is shown below.

$$S^2 = \frac{\text{Total resistance of all electric detonators}}{\text{Total resistance of all lead wires, connecting wires, buswire}}$$

However, it is important to realize that this method and the associated equation is applicable only when blasting with a power source that provides a constant voltage to the circuit. This means that a blaster using a power line can use this equation but a blaster with an ordinary condenser discharge machine should not depend on it. (Carlos Delgado, an ISEE member from Lexington, KY, has done an extensive study of the use of a blasting machine and the optimum number of series.. Anyone interested in the details should contact him.)

Consider the example used earlier; suppose a blaster has loaded a shot using 240 electric detonators, each with a resistance of 2.1 ohms. If the lead line resistance has been measured or calculated to be 4.0 ohms, and the connecting wire has been calculated to be 2.25 ohms, what is the best way to wire the circuit?

According to this equation:

$$S^2 = \frac{240 \times 2.1\ \Omega}{4.00\ \Omega + 2.25\ \Omega} = \frac{504\ \Omega}{6.25\ \Omega} = 80.6$$

$$S = \sqrt{80.6} = 8.98. \rightarrow 9 \text{ series}$$

The formula indicates that in this case, the best number of series to use would be nine. However, the blaster would find that 240 cannot be divided equally into 9. In order to balance the series branches, he may add three more detonators to make a total of 243, which can be divided evenly into 9 series of 27 caps each.

At this point in the calculations, the blaster has determined only that 9 series of 27 detonators each is the best way to wire this shot. Even wired in this manner, the blaster still cannot be certain that the detonators will receive sufficient current to reliably fire. While this S^2 formula will yield the best combination to use, a power supply which is too small or one whose voltage is too low, will not reliably fire the circuit regardless of the configuration. Since the current and energy available to the circuit is dependent on the power supply, the blaster must still use the resistance and current calculations to ensure that the circuit will receive adequate power.

Continuing with the example above, would a power source of 440 volts AC provide sufficient current to fire the detonators? To determine whether it would, requires a blaster to first calculate the resistance of the circuit. Twenty- seven detonators at 2.1 ohms per detonator produce a total resistance of 56.7 ohms per series, When the nine series are connected into parallel with each other, the total resistance of the detonator circuit is 56.7 ohms divided by 9 series, or 6.3 ohms. The resistance of the lead line is 4.0 ohms, and the connecting wire is 2.25 ohms, so the total resistance of the entire blasting circuit is:

$$R_t = 6.3\Omega + 4.0\Omega + 2.25 = 12.6\Omega$$

Applying Ohms Law, the current provided to the entire circuit is:

$$I = \frac{440 \text{ volts}}{12.6 \text{ ohms}} = 34.9 \text{ amps}$$

The 34.9 amps of current supplied by the power source is divided equally among the nine balanced series. Each series receives 3.87 amps (34.9 ÷ 9). Each detonator in the series will therefore receive this amount of current. According to a generally accepted standard, the minimum firing current using an AC power source is 2.0 amps per series. Since the available current of 3.87 amps exceeds this value, the circuit as wired will reliably initiate all detonators.

Consider, however, if a 120 volt power source is used in an attempt to fire this same circuit. Ohm's Law as applied would show that the current available is:

$$I = \frac{120 \text{ volts}}{12.6\Omega} = 9.52 \text{ amps}$$

Again, the 9.52 amps is provided for the entire circuit, which must be divided among 9 series. Therefore, each series receives 1.06 amps (9.52 amps ÷ 9). This value is well below the minimum recommended firing current of 2.0 amps AC, and the blaster risks the possibility of misfire in this case. Again the calculation of current using Ohm's Law is restricted to power sources with a constant voltage; use of a blasting machine requires the blaster to consult a graph or table of output current for various circuit resistances.

GENERAL NOTES ON WIRING

If the number of detonators to be fired in a shot cannot be divided evenly into a number of balanced series, the blaster must decide carefully how to handle it, In the example above, there were 240 detonators which could not be divided evenly into 9 series. The solution mentioned was to add 3 detonators to make a total of 243, which can be divided into 9 series of 27 caps each. These three additional detonators may or may not be loaded into boreholes.

Another possibility is to wire six series with 27 detonators and three series with 26 detonators. In this case, the difference of one detonator or 2.1 ohms between series would not affect the current distribution significantly However, whether this can be safely done in other cases will depend on the amount of current available above the minimum required, and the resistance of a single detonator. If the current being provided by the power source is close to the minimum value, it would be best to add detonators as illustrated in the first method above and eliminate any possibility for a partial misfire due to uneven current distribution.

It is also important to keep in mind that it is actually resistance that is the determining factor in deciding whether series are balanced. Series containing detonators with different leg wire lengths will create unbalanced series if you consider only the number of detonators per series. A series of twenty-five detonators with 16 ft. leg wires has a total resistance of 47.5 ohms; a series of twenty-five detonators with 28 ft. leg wires has a total resistance of 60 ohms. Should these two series be wired in parallel with each other, they would be seriously unbalanced.

When a blaster performs all his resistance and current calculations and finds that he is near or below the minimum required current, what are his options? Assuming he has split the shot into the optimum number of series according to the S^2 formula, he can gain nothing by increasing the number of branches above this number, in fact, current received by each detonator will decrease.

The best and most obvious option is to use a larger power source, either a larger capacity blasting machine or a higher voltage. Another possibility is to decrease the resistance of connecting wire or lead line. However, this should never be done by shortening the length of the lead line, because this can easily lead to a less safe initiation. However, the resistance of both the lead line and the connecting wire can be decreased through the use of heavier or higher gauge wire.

All wiring calculations in these examples are based upon good wiring practices. Poor splices and connections can contribute an unknown but significant amount of resistance to a circuit. Mechanically tight, clean splices have negligible resistance. If the ends of the lead line are dirty or oxidized, sandpaper can be used to clean the bare ends. Connecting wire from a previous blast should never be reused, since it may have sustained damage from flying rocks or stresses that are not readily visible. The insulation of lead line should be checked often as it is being unrolled, and all wire used on a blast should be made of single strand, solid copper.

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