INFLUENCE OF PRIMARY CHARGE LOAD PRESSURE ON FUNCTION TIME AND SENSITIVITY OF A HOT WIRE DETONATOR

By

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IN THE NAME OF ALLAH
THE GRACIOUS, THE MERCIFUL

“If Allah is your helper none can overcome you, and if He withdraw His help from you, who is there who can help you? In Allah let believers put their trust”

(Al-Imran-160)

DEDICATED

To

My Elders & My Family

Who Always Pray For My Success

in This World & The World Hereafter!

ABSTRACT

Detonator is an explosive element which is used in various devices for the initiation of high explosives and classified according to their external initiation mechanism. Hot wire detonator is initiated thermally by electrical means.

Function time is one of the important performance parameters of the detonator. It is very critical, especially, where synchronization is required in explosive bolts, during release of several motor ports, in multipoint initiating devices, blasting mines etc.

The objective of the project is to study the effect of primary charge load pressure on function time, measured using photo diode sensor and oscilloscope, of a hotwire detonator taking Dextrinated Lead Azide as primary charge and PETN as intermediate and base charge. The project also includes the experimental studies of the variation of function time depending on the nature of the primary charge. Behavior of Lead Styphnate and Lead Azide were compared.

When the load pressure on the primary charge filled in the flushed wire-bridge detonator was increased, results showed that function time and dispersion decreased. In case of DLA it was observed that it became insensitive at 80 Mpa whereas Service Lead Azide remained sensitive even at 300 Mpa. Nature of primary charge also has significant effect on the function time.

In the light of these results, function time of a hot wire detonator can be decreased, made precise and reproducible, and also, at the same time, no fire capability at safe current can be improved with increase in primary charge load pressure to meet specific requirements.

ACKNOWLEDGEMENT

In the name of Almighty **Allah**, who gave me the courage and helped me to complete the work. I feel my privilege and pleasure to express my profound and cordial gratitude to my honorable supervisors **Dr. A. Q. Malik** and **Dr. Muhammad Zaman Sheikh** for their valuable guidance, skilled advice and ever-encouraging attitude throughout the work. Under their kind and scholastic guidance and consistent encouragement this work got its present shape. Special thanks to **Dr. K. Sanauallah** and **Dr. M. Bilal Khan** for their encouraging attitude. I am thankful to **Dr. Muhammad Akram,** Director, KRL for permitting to use KRL lab facilities. I am also thankful to KRL officers and technicians for their co-operation and help in experimental work.

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GENERAL INTRODUCTION

The first element of the explosive train is an initiator which may be an igniter or a detonator depending on the type of the explosive to be initiated.

1.1 Igniter

It is an explosive device that is used for initiation of explosives which need flame or flash for their initiation instead of a shock wave. This kind of explosives is known as deflagrating explosive. There are several means for initiation of these explosives like friction, flash, stabbing and percussion.

1.2 Detonator

It is an explosive device that is used for initiating explosives where a shock wave is required. Explosives of this kind are known as high explosives.

The first blasting cap or detonator was demonstrated in 1745 by Dr. Watson in 1750; Benjamin Franklin in Philadelphia made a commercial blasting cap consisting of a paper tube full of black powder with wires leading in both sides. The two wires came close but did not touch, so a large electric spark discharge between the two wires would fire the cap.

In 1822, first hot wire detonator was produced by Dr Robert Hare, using one strand separated out of a multi-strand wire as the hot bridge wire. This blasting cap ignited a pyrotechnic mixture (believed to be potassium chlorate / arsenic / sulphur) and then a charge of pressed black powder.

In 1864, Alfred Nobel introduced the first Pyrotechnic Fuse blasting cap, using mercury fulminate to detonate dynamite. In 1868, H. Julius Smith introduced a cap that combined a spark gap igniter and mercury fulminate, the first electric cap able to detonate dynamite. In 1875, Perry "Pell" Gardiner and Smith independently developed and marketed caps which combined the hot wire detonator with mercury fulminate explosive. These were the first generally modern type blasting caps. Modern caps use different explosives and separate primary and secondary explosive charges but are generally very similar to the Gardiner and Smith caps. Electric match caps were developed in early 1900s in Germany and spread to the US in the 1950s [13] Detonators are commonly placed into two groups, namely mechanical or non-electric and electric.

1.2.1 Mechanical or Non-Electric

These are divided into following major categories according to the mechanism of initiation.

1.2.1.1 Fame or spark detonator

These detonators contain flash sensitive charge at input end of the detonator which detonates instantly upon exposure to spark, hot particles or flame.

1.2.1.2 Stab Detonator

It is initiated when a needle, usually spring loaded, is allowed to strike and penetrate the top layer of the stab sensitive composition. Hot spots are created by frictional forces between needle and explosive as well between explosive particles themselves.

1.2.1.3 Percussion Detonator

Contrary to stab initiation, the blunt firing pin does not puncture the case in percussion initiation. Rather the pin squeezes the priming mix between the cup and anvil.

1.2.2 Electric Detonator

1.2.2.1 Conductive Film Electric Detonator

In this detonator, both metallic and semiconductor films are used as bridge. Working principal of Film Bridge is same as Wire Bridge electric detonator. Semi conductor bridges used for military purposes are usually made of graphite.

1.2.2.2 Conductive Explosive Mix Electric Detonator

Electrically conductive mixtures are prepared by mixing explosives with metals or other conductive materials in which sufficient current density results in initiation of a self propagating reaction of the explosive. Metals in flake or powdered form, graphite and acetylene black are used for the conductive component of the mixture while both common primary and secondary explosives are used as explosive component.

1.2.2.3 Spark Gap Detonator

Electric sparks produced by applying high voltage between electrodes are used for initiation of the detonator. The energy required for initiation of the detonator is highly dependent upon physical and electrical characteristics of the discharge system and the nature of initiating explosive.

1.2.2.4 Slapper Detonator

It is initiated with a shock from a tiny flyer plate that is driven into the main charge of secondary explosive. Pyrotechnic source or electrically exploded foil can be used for driving the flyer plate. [12]

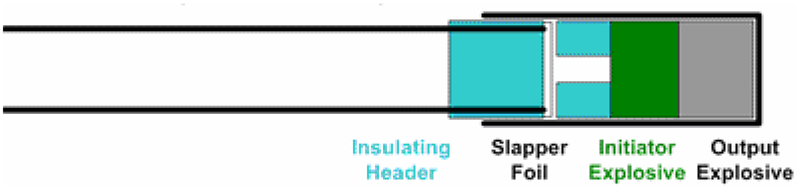

Figure 1.1 Slapper detonator

1.2.2.5 Exploding Bridge-wire Detonator

These detonators use shock wave for their initiation. Shock wave is produced from an electrically exploding wire to initiate insensitive explosives directly, without use of sensitive primary explosives. As the initial charges of the detonator are secondary explosives like PETN or RDX, therefore, they are relatively safe from initiation by direct application of heat and external influences (impact or vibration) or from electrical input except the highly specified pulses for which they are designed.

1.2.2.6 Hot Wire Detonator

A hot wire detonator is initiated with heat energy produced by electrically heated bridge-wire to a temperature sufficient to cause initiation of the primary explosive in contact with it. The hot-wire detonator has advantages of its simplicity, low cast and easier firing.

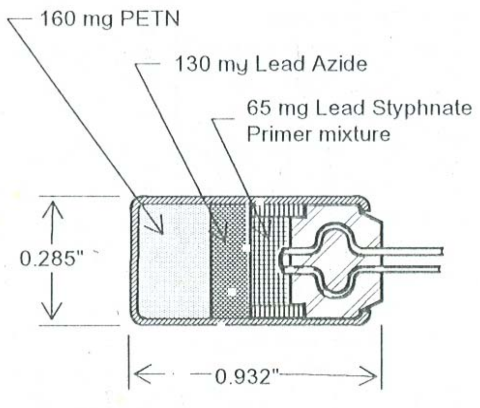

Figure 1.2 A typical military hot wire detonator

The electrical energy is converted into a thermal impulse by one of five basic systems: the bridge-wire, semi-conductor bridge, exploding bridge-wire, spark gap and conductive mix. [1]

1.3 Initiating Charge

The explosive in direct contact with bridgewire is known as flash charge. This high energy heat sensitive charge placed having intimate contact with bridgewire provides reliable fast response to the initiating impulse. Common initiating charges are lead styphnate, lead azide, lead mononitroresorcinate, tetrazine, mercury fulminate etc. Following techniques are used to apply these charges to the bridgewire. [14]

1.3.1 Beading

A bead is built up on the bridgewire by applying coating of a nitrocellulose-laquer slurry of the pyrotechnics by small brush stokes. It is difficult to attain consistent uniform beads or high charge density by this technique.

1.3.2 Buttering

A wet paste is buttered directly into a cavity that contains exposed bridgewire. It is important that the mixture be completely dry before sealing and care must be taken to avoid damaging bridgewire.

1.3.3 Loose powder

Powdered charges may simply be poured into the cavity containing the bridgewire. Intimate contact between the bridgewire and the charge materials is not insured by this technique.

1.3.4 Pressing

Pressing the loose powered charge insures intimate contact with heating element. The bridge-wire must be flush mounted against the insulated header to withstand the load. Since the bridge-wire is in contact with the header, this system has higher heat losses that occur in systems in which bridge-wire is completely surrounded by their charges.[14]

1.4 Intermediate Charge

An explosive composition is initiated or detonated via an explosive train. The detonator explosive train is an arrangement of explosive components containing primary charge, intermediate charge and base charge. The primary charge burns to detonation. This detonation is intensified and transmitted to the base charge to maximize output. Lead azide can be used as intermediate charge.

1.5 Base Charge or Secondary Charge

Base charge is placed at the output end of the detonator to maximize output. The base charge of most electric detonators is PETN.

1.6 Bridge Types

Bridges are usually divided into two classes, namely, raised bridges and flush bridges.

1.6.1 Raised Bridges

It is not in contact with the header. Primary charge surrounds the bridge-wire completely. Raised bridges are usually made fine round cross-section wires. These bridges are either soldered or welded to conductor pins.

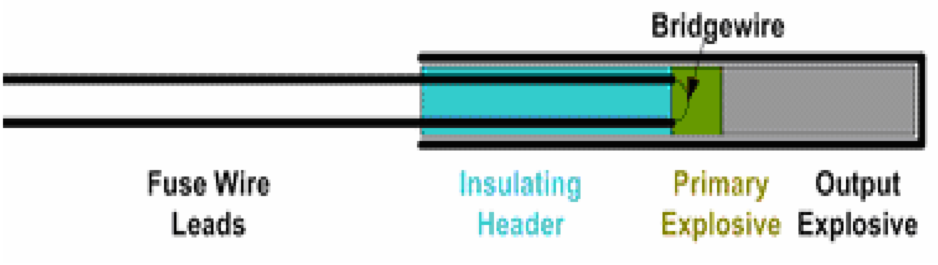

Figure 1.3 Raised bridge detonator

1.6.2 Flush Bridges

These bridges are flush to the surface of the header. As the bridge-wire is in contact with header, therefore, energy losses are higher.

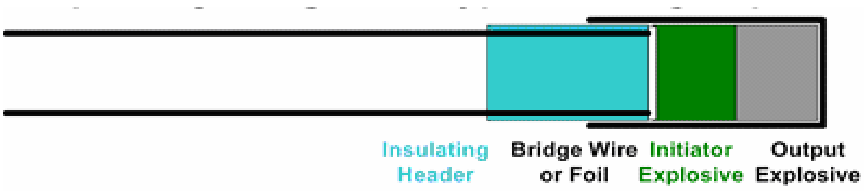

Figure 1.4 Flushed bridge detonator

Flush bridges may be in the form of the wires, ribbons, foils or deposited films. Bridges are made by soldering, welding and the deposition process for deposited films.

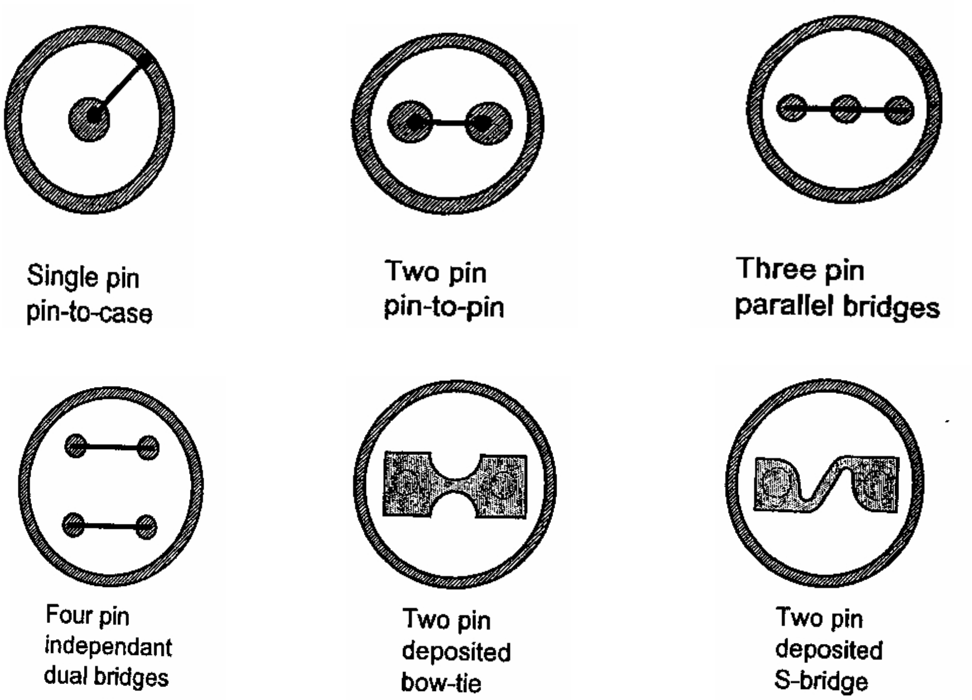

Figure 1.5 Typical bridges and bridge configurations of flush bridge initiators

1.7 Bridge Materials

Usually metals either pure or alloyed are used as bridge materials. Common pure metals used are gold, platinum, tungsten and chromium and typical alloys include various nichrome types, platinum/ iridium, gold/iridium, gold/rhodium, and platinum/rhodium. [3]

FUNCTION TIME

The total function time of an electric initiator is defined as the time from the input signal supplied to the initiator and the appearance of flash when it ruptures.

Function time,T_f, is the sum of the time taken from the beginning of the firing energy and start of burning reaction, t_e, and the transition time, t_t, time taken from the start of burning reaction until the initiator ruptures at the end.

$$T_f = t_e + t_t$$

Performance of a hot wire detonator is evaluated on no-initiation at safe current, satisfactory initiation at all-fire current, desired function time and reliable ignition strength to detonate boost charge. Ignition delay time is a very critical parameter because of its following applications in various explosive devices.

2.1 Importance of Function Time

- Simultaneous initiation of Several exploding bolts for separation Explosive cords for destruction
- Simultaneous release of several motor ports to effect thrust termination, neutralization, or reversal.
- Simultaneous ignition of several rocket motors

- Systems where timing sequenced functions is required to be in the range of microseconds to milliseconds, as, for example, during a first stage separation, second stage motor ignition.
- Simultaneity needed for multipoint initiation of several electro-explosive devices, mainly for use in plutonium-based nuclear weapons in which a plutonium core (called a "pit") is compressed very rapidly. This is achieved via conventional explosives placed uniformly around the pit. The implosion must be highly symmetrical or the plutonium would simply squirt out at the low-pressure points. Consequently, the detonators must have very precise timing.
- Very precise timing is required for multiple point commercial blasting in mines or quarries.
- Precise time is required in proximity fuzes used in warheads of surface to air and air to air missiles. [14]

2.2 Parameters Influencing Function Time

Function time depends on the following parameters.

- Nature of primary charge
- Density or loading pressure
- Condition of confinement
- Bridge-wire characteristics
- Firing condition

2.3 Project Objective

The objective of the project is to study the effect of primary charge loading pressure on function time and sensitivity of a hotwire detonator using lead azide as primary charge and PETN as intermediate and base charge. The project also includes the experimental studies of the function time of the detonator depending on the nature of the primary charge, using first lead styphnate and second lead azide as primary charge with PETN as intermediate and base charge.

2.4 Rosenthal Equation

Before supplying electrical energy, the temperature of the bridgewire and surrounding charge is equal to the ambient temperature. When the electrical energy is supplied, current passes through the bridgewire of the detonator. The bridgewire is heated by the current passing through it. Part of this heat goes to raise the temperature of bridgewire and rest of heat is dissipated to bridgewire surroundings owing to thermal conduction. The ignition of the primary charge occurs as a result of raising the temperature of a very small critical region, may be one or two mils, to the ignition temperature of the explosive surrounding the bridgewire. As the critical region is very small, so it is assumed that if any portion of the bridge is heated to ignition temperature, initiation will result. Thus, the analysis of initiation behavior of hotwire detonator is reduced to a simple calculation of the bridgewire temperature.

Using these concepts Rosenthal proposed that hotwire initiator could be described by the following equation. [6]

$$C_p\,(dT/\,dt) + aT = P_{(t)} \tag{1}$$

Where,

C_p Heat capacity of bridge wire which depends on volume and material of wire

T Temperature rise from ambient temperature

a Heat loss (heat transfer from wire-bridge to pins, primary charge on one side and header on the other side).

$P_{(t)}$Input electric power

$$P(t) = I^2R \tag{2}$$

The current “I” depends on input power supply.

For capacitor discharge supply

$$I(t) = (V/R) \exp(-t/RC) \tag{3}$$

Equation no.1 shows that input electrical power is distributed into two parts. One part goes to heat the bridgewire and other is dissipated through heat conduction from bridgewire to the leads, the explosive charge and header (in case of flash bridge).

$C_p\, dT/dt$.............part of input power which goes in raising bridgewire temperature

$a.T$......................part of input power which is dissipated or lost through heat conduction

Lead azide is a poor conductor. At low pressure, bridgewire and primary charge have poor contact intimacy. Also there are quite numerous interstitial spaces containing air in the loaded primary charge surrounding bridgewire. Specific heat of air is less than lead azide. These factors contribute in heat dissipation or heat losses. So, at low loading pressures heat losses are obviously greater. With increase in loading pressures, charge density increases and the spaces in the charge become less enormous. Contact intimacy of bridgewire with explosive granules also increases. Therefore increase in pressure reduces heat losses which results decrease in function time.

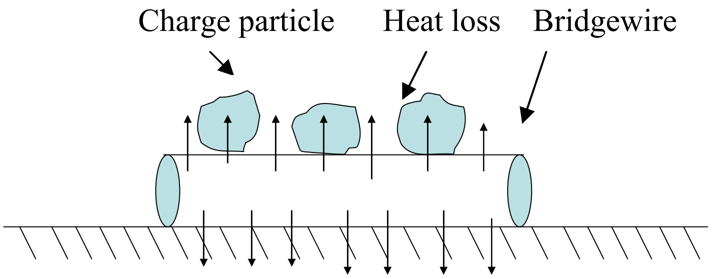

Figure 2.1 Heat loss from bridgewire

When the pressure is continuously increased, at high pressures, the insensitivity of the primary charge is dominated by increase in density and more energy is required for initiation.

FUNCTION TIME MEASURING TECHNIQUES

Depending on the measuring equipment selected, the methods for measurement of function time can be divided into: [9]

- The optical methods which are based on the use of different types of high-speed cameras.
- The electrical methods which are based on the use of different types of probes combined with an electronic counter or an oscilloscope.

3.1 Optical Methods.

Detonation is accompanied by the emission of light. This makes it possible to view the explosion using optical methods which are based on the use of different types of high speed cameras.

Different types of high-speed cameras that are in use may be classified into the following groups with respect to their operating principle:

- Rotating-drum cameras.
- Rotating-mirror streak cameras.
- Rotating-mirror framing cameras.
- Electronic cameras.

The main parts of the rotating-drum camera are a hollow drum, an electric motor, an electronic synchronization system and a time pulse generator.

Two types of rotating-drum cameras exist:

- Camera in the film track is mounted on the external drum surface.
- Camera in which the film track is mounted on the inside drum surface.

The streak cameras, in addition to optical part, have an electronic part which provides:

- The initiation of an explosive charge at a definite time.
- An accurate determination and regulation of the camera mirror velocity.

The rotating-mirror streak cameras have a writing speed of a few mm/us, which is some ten times greater if compared to the rotating-drum cameras.

The optical part of the framing camera includes an objective lens, a field lens, a rotating mirror and relay lenses. As the mirror rotates, the image of the event is formed on the film track, yielding a sequence of pictures. Speed of the camera depends upon angular velocity of the mirror.

In an electronic camera, the image is formed on the photocathode via the objective lens. By means of the focusing electrode and an anode, the optical image is converted into an electron beam, which forms a sharp image of the event on the phosphorous screen. The image from the screen is photographed on a polarized film or a high speed negative film. Electronic cameras can operate in streak or framing mode.

3.2 Electrical Methods

Principle of this method is based on closure or breakage of the electrical circuit by means of probes which operates on the arrival of the detonation wave. The signal produced is sent to the electronic counter or recorded by fast storage oscilloscope.

The probes capable of detecting detonation wave may be of various types depending on their operating principle and are divided into:

- Ionization Probes
- Electro-contact probes

3.2.1 Ionization Probes

The operating principle of the ionization probes is based on the fact that detonation products behind the detonation front are highly ionized, which makes them capable of conducting electric current. Thus, the arrival of the detonation wave at an ionization probe, which is actually an electric switch, enables the closure of the electric circuit. That allows a capacitor to discharge and the associated voltage signal is sent to the electric counter or fast storage oscilloscope.

Ionization probes depending on their design they are divided into:

3.2.1.1 Twisted Copper Wire Probe

It is the simplest design ionization probe. The probe is made of two twisted copper wires, one of them with, and the other without, insulation. During testing, the twisted part of the probe is inserted into output end of the boost charge and then subtracting the travel time of the detonation wave through the booster.

This type of probe is frequently used, however, when explosive of very low detonation power are tested, the probability of the detonation wave detection is considerably decreased because of the decreased ionization effect in such detonation waves.

Figure 3.1 Twisted copper wire Probe

3.2.1.2 Pin Ionization Probes.

The frequently used ionization probe is the so-called pin ionization probe. The electric conductor inserted into the explosive charge serves as common electrode. It is a noninsulated copper wire or strip 1 mm in diameter. The other two electrodes are steel pins placed perpendicularly to the common electrode at a distance 0.3~0.5 mm from it. When the detonation wave arrives at the pin, the electric contact between the common electrode and the pin is restored due to ionization effect in the detonation wave.

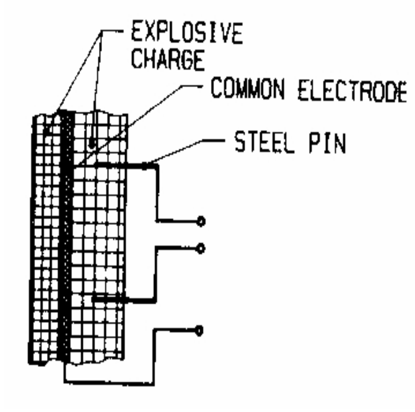

Figure 3.2 Pin ionization probe

3.2.1.3 Stripped Ionization Probes

Instead of steel pins stripped, both electrodes are thin copper foil, 40 um thick and 3 mm wide. They are placed in the explosive charge at a distance of 1~3 mm between them. The principle of the detection of the detonation wave arrival is the same as in the other ionization probes.

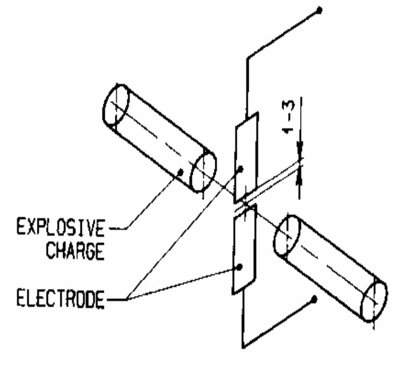

Figure 3.3 Stripped ionization probe

3.2.2 Electro-contact or Mechanical Probes

Closure or breakage of the electrical circuit by means of these probes is accomplished mechanically due to a detonation wave pressure action. The electrocontact type of probe according to Amster and Beguregad consists of a long copper wire. The insulation is removed from the middle part of a wire. The wire is then placed into a copper tube. The wire insulation prevents the electric contact between the wire and the tube. During the experiment, the probe is placed into a hole made in the explosive charge. By the arrival of the detonation wave, the copper wire will be squeezed under the action of the detonation wave pressure, and the electric contact between the copper wire and copper tube will be realized.

The electrocontact type of probe according to Campbell consists of two conducted rectangular metal foils between which a thin insulation foil made of nylon, mica, etc. is placed. The electric contact between two metal foils is realized by the action of the arriving detonation wave.

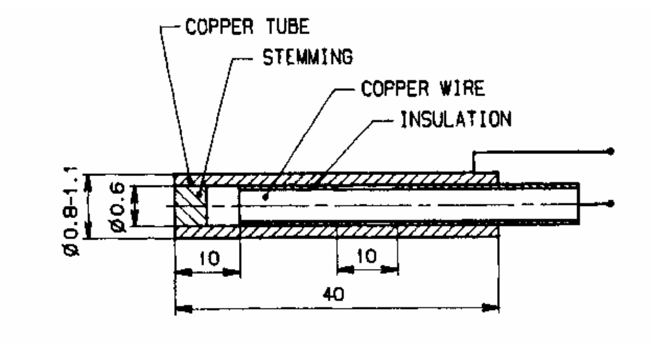

Figure 3.4 The electro-contact probe according to Amster & Beguregad

The wave action causes the first foil to start moving, consequently crushing the insulation foil and closing an electric circuit.

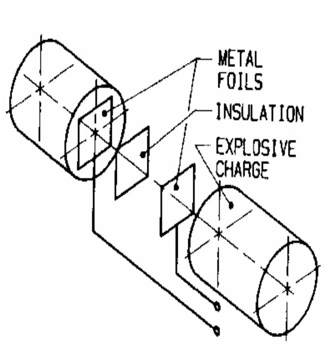

Figure 3.5 The electro-contact probe according to Campbell

Irrespective of the probe type used for determination of the ignition delay time when an electronic counter/ electro-contact probes technique is applied, the way the initial signal produced by the closure of an electric circuit is transformed into the corresponding signal that starts or stops the counting assembly of the electronic counter is the same: the probes leads are connected to a resistance-capacitance(RC) assembly that produces sufficient voltage signal to start/stop the counting assembly of the electronic counter.

3.2.3 Photo sensor diode

A photodiode is a type of photo detector capable of converting light into either current or voltage, depending upon the mode of operation.

Photodiodes are similar to regular semiconductor diodes except that they are packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device.

3.2.3.1 Principle of operation

A photodiode is a PN junction or PIN structure. When a photon of sufficient energy strikes the diode, it excites an electron thereby creating a mobile electron and a positively charged electron hole. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

To record the functioning times, following instruments are usually used for having good time resolution.

3.3 Electric Counter

The electronic counter operates on the principle of continuous generation of pulses from an oscillator, which are consequently registered by a counting assembly. An electronic switch enables the passages of the pulses to the counting assembly during interval only, which is limited with the signals for starting and stopping of the counting assembly.

3.4 Oscilloscope

A dual beam oscilloscope is used to record the time difference between two time – related pulses of two separate events. Function time is measured by calculating time difference between oscilloscope triggering signal, the potential drop across the detonator when the switch is closed, and output signal received when the detonator ruptures through photo sensor diode or electrical probes.

EXPERIMENTAL WORK

4.1 Experimental Set Up

The determination of the function time is based on the ability of photo sensor diode to accept a light emerged from detonation of the detonator and to transmit the same into electric signal that was recorded by a fast-storage oscilloscope.

This method was used for the experiment as this optical method has proven to be reliable, simple and convenient.

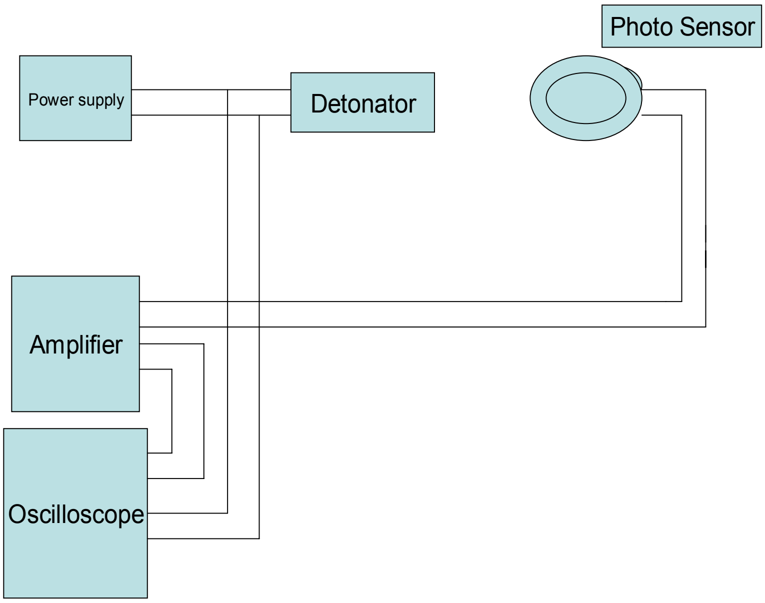

Figure 4.1 Schematic Diagram for measuring function time of hot wire detonator

The firing circuit consisted of a 24 V, 1 Ampere power supply which charged the capacitor through a 220 ohm resistor. The circuit employed a micro switch to discharge the capacitor through the detonator**.**

A Techtronic Dual Beam oscilloscope was used to record the functioning time. The potential drop across the detonator provided the triggering signal for the oscilloscope, when the switch closed.

In this method the light emitted from the detonator on detonation was transmitted to BPY61(8602) photo diode. The electrical signal from photodiode was amplified and transmitted to the input of one channel of the oscilloscope. The function time was measured as the time from the beginning of the oscilloscope sweep to the beginning of the light signal.

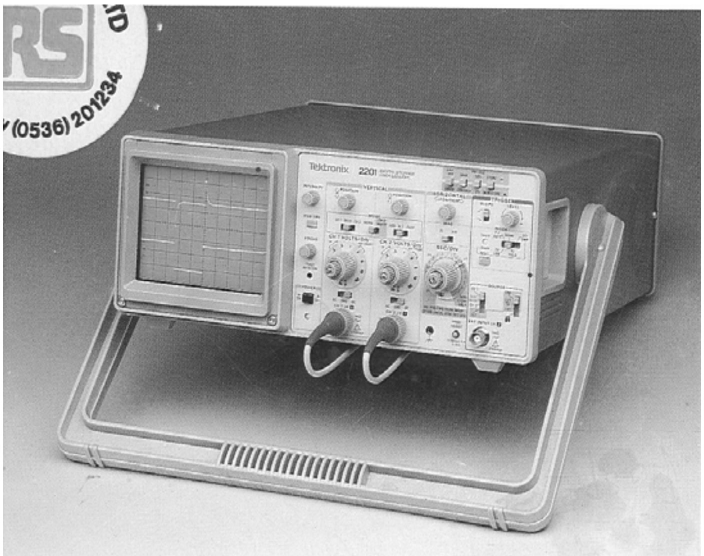

Figure 4.2 Tektronix 2201 Digital Storage Oscilloscope

4.2 Time Difference Measuring Procedure:

To measure time difference, following procedure is adapted.

- Preset the instrument controls and obtain a baseline trace.
- Set the trigger source switch to CH1.

- Set both AC-GND-DC switches to the same position, depending on the type of input coupling desired (AC or DC).
- Using probes with equal time delay, connect the reference signal to the CH1 and the comparison signal to the CH2.
- Select Both Vertical Mode; then select either ALT or CHOP, depending on the frequency of the input signals.
- Set both VOLTS/DIV switches for division display.
- Adjust the Trigger LEVEL control for a stable display.
- Set the SEC/DIV switch to a sweep speed which provides horizontal separation between the reference points on the two displays.
- Measure the horizontal difference between the two signal reference points and calculate the time difference using the following formula:

Time Difference = (SEC/DIV Setting X Horizontal Difference (div))/(Magnification Factor)

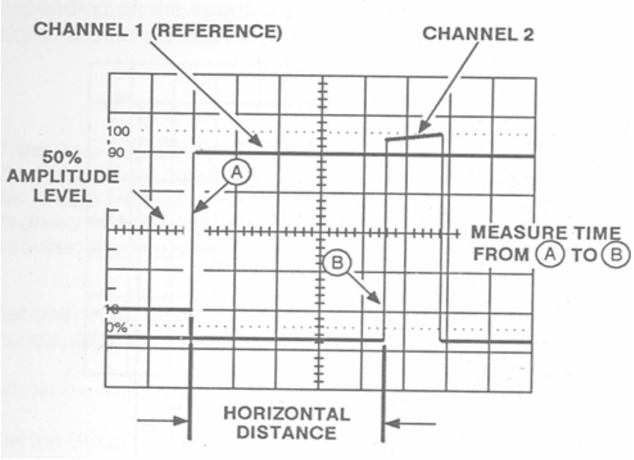

Figure 4.3 Time difference between two time-related pulses

Example: The SEC/DIV switch is set to 50 us, the Horizontal MAG switch set to X10, and the horizontal difference between waveform measurement points is 4.5 divisions.

Substituting the values in the formula:

$$\text{Time Difference} = (50\ \text{us/div} \times 4.5\ \text{div}) / 10 = 22.5\ \mu\text{s}.$$

4.3 Detonator Test Samples

4.3.1 Components

- A tube/cup
- Reinforced/strength cap
- Plug
- Primary charge
- Intermediate charge
- Base charge
- Bridge-wire
- Two single strand insulated copper wires

4.3.2 Hardware Characteristics

4.3.2.1 Case/Cup

- Light weight.
- Good corrosion resistance.
- Compatible with the explosive used.

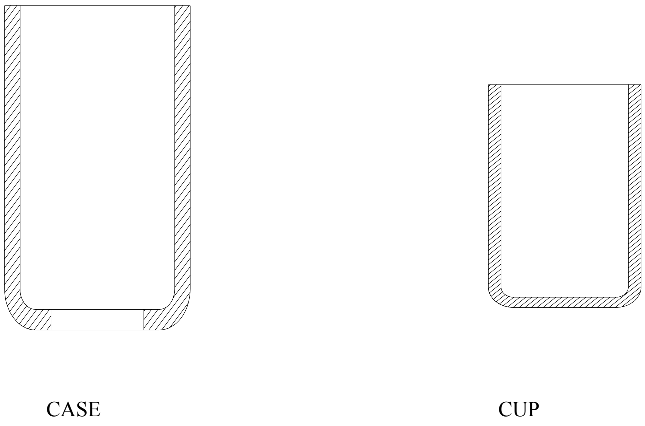

Figure 4.4 Case and Cup

4.3.2.2 Plug

- Desired strength.
- Good heat insulator.

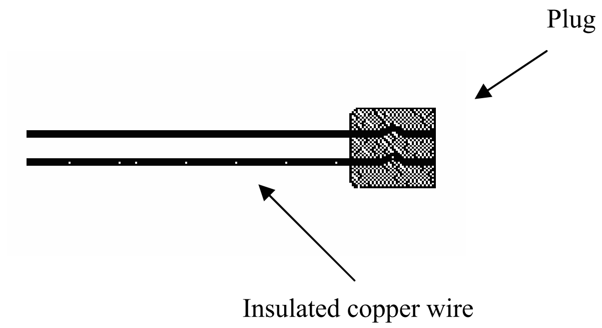

Figure 4.5 Plug with insulated copper wires

4.3.2.3 Bridge wire

- Explosive compatibility.
- Good corrosion resistance.
- Higher strength.
- Favorable electrical properties.

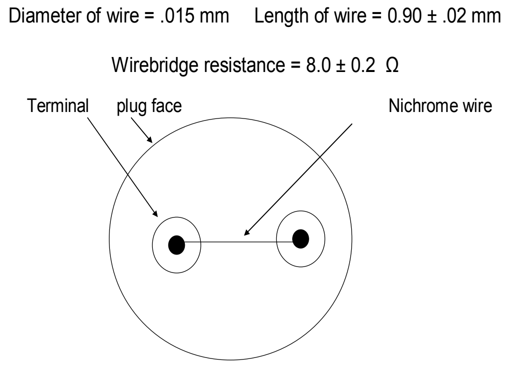

Figure 4.6 Nichrome wire-bridge

4.4 Explosive Characteristics

4.4.1 Dextinated Lead Azide

i. It is an impure form and contains approximately 93% lead azide, 4% lead hydroxide and 3% dextrin and impurities.

ii. White to buff in colour
iii. Sensitive to shock initiation.
iv. Specific heat value in compressed form: 1.55 cal/gm /ºC.
v. Absolute density: 4.38 gms/cm^3.
vi. Detonation velocity 3900 m/sec pressed at a density of 2.62gms/cm3.
vii. Temperature of explosion 390 ºC.
viii. An excellent initiating agent for high explosives.

Its superior initiation action, complete stability from a practical view point, low cost, and greater availability of its raw materials make lead azide the most important initial detonating agent for military use. [4]

4.4.2 Service Lead Azide

i. Very fine crystals, like fine white sand.
ii. More sensitive than DLA.
iii. Absolute density about 4.8 g/cm^3.
iv. Ignition temperature varies from 320º to 390º C.
v. Maximum detonation velocity 4,500 m/sec at a density of 3.8 g/cm^3. [4]

4.4.3 Service Lead Styphnate

i. Light orange or reddish brown rhombic crystals containing a molecule of water of crystallization.
ii. Relatively poor initiator of detonation.
iii. The crystal density 3.02 gm/cm^3 but the apparent density only 1.4 to 1.6 g/cm^3.
iv. More sensitive to impact than lead azide.
v. Explosion temperature 282º C, which is less than lead azide.
vi. Detonation velocity 5200 m/sec pressed to a density of 2.9 g/cm^3. [4]

4.4.4 PETN (Pentaerthrite Tetranitrate)

i. White or light buff in colour.
ii. Crystal density: 1.765 g/cm^3.
iii. Slightly more sensitive to impact than RDX.
iv. Minimum temperature of explosion 215° C.
v. Relatively insensitive to electric sparks.
vi. Classification on the basis of granulation, class D is used in blasting caps and detonators. [4]

4.4.5 Assembling Procedure of Detonator Test Samples

Steps adopted in manufacturing of test samples are:

A) Bridge Making

i. Elimination of Insulated lacquer from copper wire.
ii. Staining copper wire with tin.
iii. Soldering of electric bridge.
iv. Cleaning of bridge.
v. Appearance inspection of bridge.

B) Measuring resistance of bridge wire with multi-meter.

C) Annealing treatment by passing 60 mA current through the bridge for one second.

D) Measuring variation in resistance after annealing treatment.

E) Insertion of plug with soldered electric bridge into the case.

F) Primary Charge Pressing

i. Weighing of 120 mg primary charge (DLA or SLA) using balance upto 0.01 accuracy.
ii. Filling and pressing of primary charge on hydraulic press.

G) **Intermediate Charge Filling**

i. Weighing 40±10 mg PETN

ii. Loose filling of PETN on the primary charge.

H) **Secondary Charge Pressing**

Weighing of 70±10 mg PETN, filling in the strength cap and pressing at 120 MPa.

I) Pressing of filled strength cap on intermediate charge.

J) Sealing and packing of the finished detonator

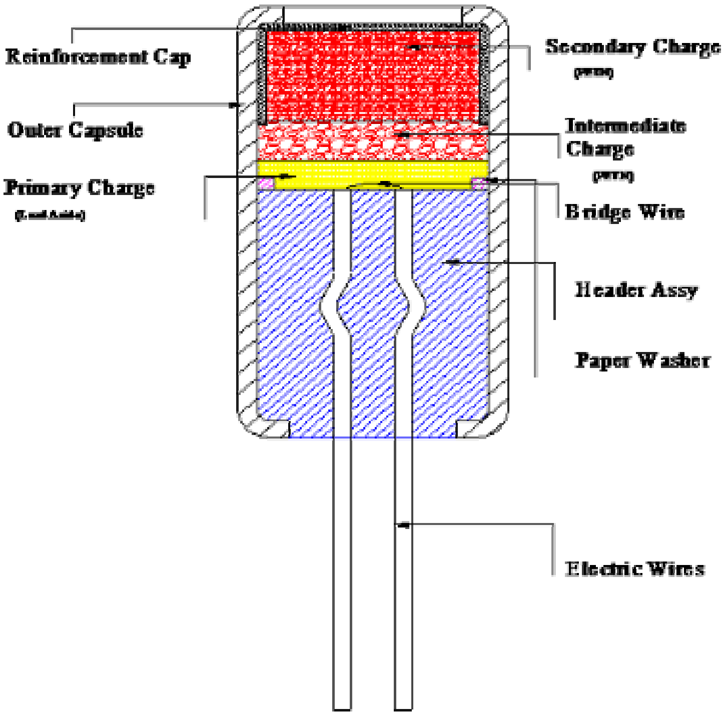

Figure 4.7Hot wire detonator

Table 4.1 Specifications of the hot wire detonator used as test sample

Wire Bridge	**Header (plug)**	**Case**
Type: Flash Material: Nichrome Length: 0.9 ±0.2 mm Dia: 0.015 mm Resistance: 8±0.2 Ω	Material: Phenolic resin Length: 3.8±0.3 mm Dia: 5.4±0.075 mm	Material: Aluminium Length: 10. ± 5 0.24 mm Outer Dia: 6± 0.048 mm Inner Dia: 5.4 ±0.048 mm
Cup	**Strands**	**Sleeves**
Material: Aluminum Length: 3.4± 0.18 mm Inner Dia: 4.6±0.048 mm Outer Dia: 5.36± 0.048 mm	Material: Copper Length: 50±5 mm Dia: 0.56~ 0.6 mm	Material: PVC Length: 16.0±3 mm Outer Dia: 1.2 mm Inner Dia: 0.7 mm
Primary Charge	**Intermediate charge**	**Secondary charge**
Dextrinated lead azide (RD-1352) and lead styphnate (RD-1303)	40 mg PETN	PETN: 70mg at 120 MPa

Table 4.2 Detonator test samples for load pressure vs. function time

Primary Charge: **Dextrinated Lead Azide, Intermediate and secondary charge: PETN**					
Sr. No.	**Primary & intermediate charge filling pressure (MPa)**	**Manufactured Qty**	**Qualified qty**	**Rejected qty**	**Remarks**
1	5	7	5	2	Rejected in bridge-wire resistance test, annealing test, case bulging during assembly and other quality checks.
2	10	6	5	1	
3	20	7	5	2	
4	40	5	5	0	
5	60	6	5	1	
6	80	11	8	3	

Table 4.3 Detonator test samples with SLA primary charge

<table>
<tr><th colspan="6">Primary Charge:
Service Lead Azide Intermediate and secondary charge: PETN</th></tr>
<tr><th>Sr. No.</th><th>Primary & intermediate charge filling pressure (MPa)</th><th>Manufactured Qty</th><th>Qualified qty</th><th>Rejected qty</th><th>Remarks</th></tr>
<tr><td>1</td><td>80</td><td>7</td><td>5</td><td>2</td><td rowspan="6">Rejected in wire-bridge resistance test, annealing test, case bulging during assembly and other quality checks.</td></tr>
<tr><td>2</td><td>100</td><td>7</td><td>4</td><td>3</td></tr>
<tr><td>3</td><td>150</td><td>6</td><td>4</td><td>2</td></tr>
<tr><td>4</td><td>200</td><td>5</td><td>4</td><td>1</td></tr>
<tr><td>5</td><td>250</td><td>4</td><td>4</td><td>0</td></tr>
<tr><td>6</td><td>300</td><td>3</td><td>2</td><td>1</td></tr>
</table>

Table 4.4 Detonator test samples with two different primary charges

<table>
<tr><th>Sr. No</th><th>Primary & intermediate charge filling pressure (MPa)</th><th>Manufactured Qty</th><th>Qualified qty</th><th>Rejected qty</th><th>Remarks</th></tr>
<tr><td colspan="5">Primary charge: Dextrinated Lead Azide (DLA)
Intermediate and secondary charge : PETN</td><td rowspan="4">Rejected in wire-bridge resistance test, annealing test, case bulging during assembly and other quality checks.</td></tr>
<tr><td>1</td><td>30</td><td>7</td><td>5</td><td>2</td></tr>
<tr><td colspan="5">Primary charge: Lead Styphnate (LS)
Intermediate and secondary charge : PETN</td></tr>
<tr><td>2</td><td>30</td><td>8</td><td>5</td><td>3</td></tr>
</table>

RESULTS AND DISCUSSION

5.1 Load Pressure vs. Function Time

Test results of the function time for detonators manufactured with Dextrinated Lead Azide as primary charge, PETN as intermediate and secondary charge were recorded as under.

Table 5.1 Test results of load pressure vs. function time

Loading pressure (MPa)	Function Time (μ sec)					Ave (μ sec)	Standard Deviation
	1	2	3	4	5		
5	38.2	45.3	32.8	29.0	29.7	35.0	5.9
10	26.7	30.7	36.4	25.3	24.6	28.6	4.3
20	31.8	25.3	28.4	26.7	23.4	27.1	2.85
40	23.0	29.6	23.5	23.8	22.1	24.4	2.66
60	21.8	17.9	22.9	25.1	22.7	22.1	2.35
80	Not fired	Not fired	Not Fired	Not fired	Not fired	-	-

Primary and intermediate charges were loaded at various pressures ranging from 5 MPa to 80 MPa with constant loading pressure of secondary charge at 120 MPa.

When the pressure was applied on the explosive charge filled on the header with flushed wire-bridge, the charge density and the contact intimacy between the charge and bridge-wire varied.

The behavior of function time with load pressure is shown in the figure no. 5.1.

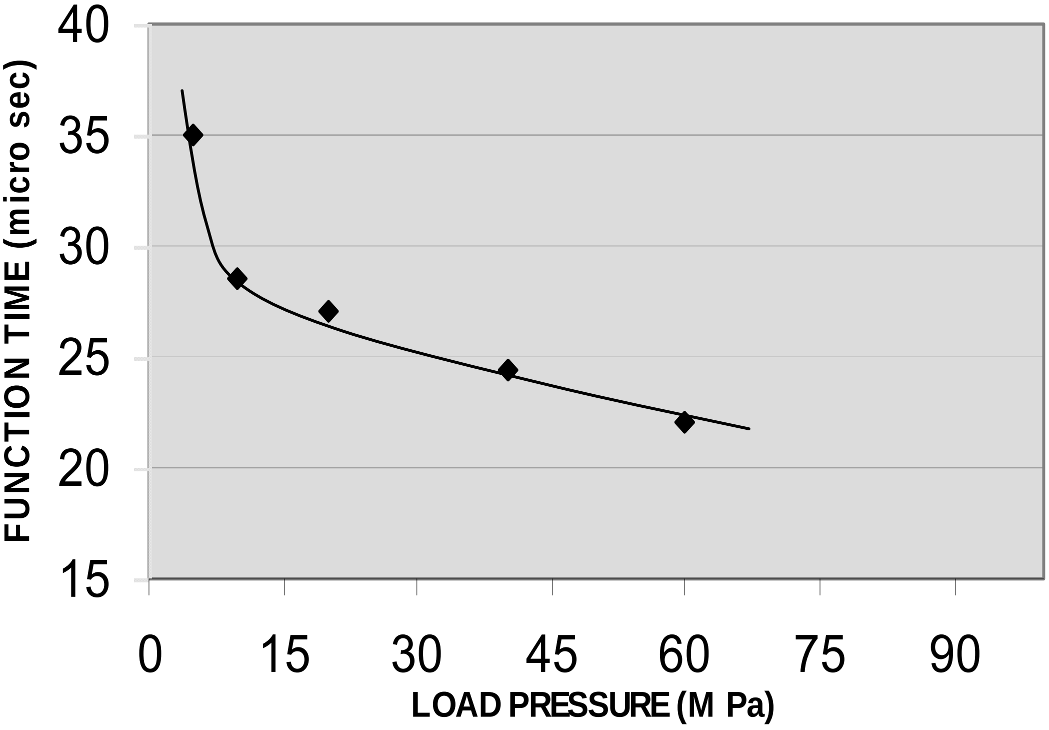

Figure 5.1 Load pressure vs. Function time

5.1.1 Charge Density Variation Effect

Charge density increases with load pressure and this increase is more prominent at low pressures. Increase in charge density increases detonation velocity and results decrease in function time. This behavior was observed in the test results.

Behavior of charge density with load pressure for Lead Azide is as under. [1]

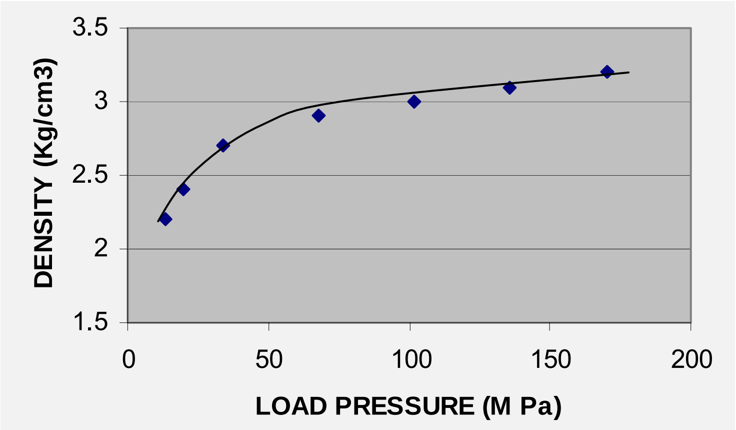

Figure 5.2 Load pressure vs. Charge density

At low pressures, there was enormous number of porosities containing air in the explosive charge. Here some heat energy was dissipated and lost through these porosities (specific heat of air is less than DLA). As the pressure continued to increase, porosities were reduced which resulted in less energy losses. This favored decrease in threshold firing energy of the detonator and hence function time decreased.

5.1.2 Contact Intimacy of Wire with Charge

At low pressures, contact intimacy between the charge and wire was poor. Wire took more time to attain ignition temperature to ignite the surrounding charge. With increase in load pressure, contact intimacy improved which increased heat flow between the wire and charge. Wire attained ignition temperature in less time. So function time decreased with increase in load pressure.

Therefore there was an overall decrease in function time with increase in primary charge loading pressure.

5.2 Load Pressure vs. Threshold Firing Energy

With continuous increase in load pressure, detonator insensitivity dominated by increase in density at 80 MPa. So, the detonators pressed at 80 MPa, were not initiated through 5 μf capacitor charged up to 24 V (energy: 1.4×10^4 ergs).

Table 5.2 Detonators initiation results through 5μf capacitor charged up to 30 V

Energy Source	Sample No.	Load Pressure (MPa)	Results
5 µf capacitor charged up to 30 V Energy of capacitor: 2.25x10^4 ergs	1	80	Bridge-wire burnt but detonator not initiated.
	2	80	Detonator initiated successfully
	3	80	Bridge-wire burnt but detonator not initiated.
	4	80	Detonator initiated successfully

Therefore, capacitor energy was enhanced by charging the same capacitor up to 30V. As this increase in the capacitor energy was at minimum level for the detonator initiation, therefore, all the detonators were not initiated. Energy was increased again by charging the capacitor up to 35 V. All the detonators were initiated successfully.

Table 5.3 Detonators initiation results through 5μf capacitor charged up to 35 V

Energy Source	Sample No.	Load Pressure (MPa)	Results
5µf capacitor charged up to 35 V Energy of capacitor: 3.06x10^4ergs	5	80	Detonator initiated successfully
	6	80	Detonator initiated successfully
	7	80	Detonator initiated successfully
	8	80	Detonator initiated successfully

5.3 Detonator Initiation Taking SLA as Primary Charge

Dextrinated Lead Azide is an impure form of Lead Azide. It became insensitive at 80 MPa and required more energy for initiation. Service Lead Azide is a pure form and more sensitive than DLA. Therefore, DLA was replaced with SLA, and test was carried out to determine its sensitivity at various load pressure.

It was seen from the results that detonators, which were not initiated with DLA pressed at 80Mpa, initiated successfully even pressed at 300 M pa without increasing firing energy.

Table 5.4 Detonator initiation results taking SLA as primary charge

Energy Source	Sample Qty	Primary Charge Loading Pressure(MPa)	Results
5 µf capacitor charged up to 24 V Energy of capacitor: 1.4×10^4 ergs	5	80	All initiated successfully
	4	100	
	4	150	
	4	200	
	4	250	
	2	300	

5.4 Load Pressure vs. Standard Deviation

Table 5.5 Load pressure Vs Standard deviation

Loading pressure (MPa) on DLA Primary Charge	Ave (µ sec)	Standard Deviation
5	35.0	5.9
10	28.6	4.3
20	27.1	2.85
40	24.4	2.66
60	22.1	2.35

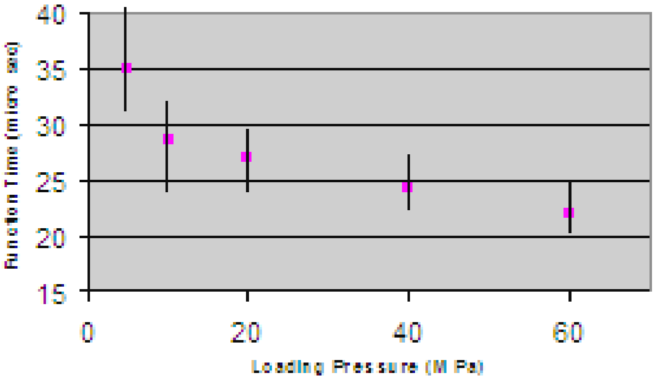

Figure 5.3 Load pressure vs. Standard deviation

Function time dispersion loaded at low pressure was higher than dispersion at high pressures. At low pressures, the probability in randomness of contact intimacy between primary charge and presence of porosities in the explosive charge were greater. Therefore greater dispersion in function time was observed. At high pressures, less dispersion was recorded due to decrease in randomness with improvement in contact intimacy and reduction in porosities.

5.5 Primary Charge Nature vs. Function Time

Table no. 5.6 shows the results of function time of two different detonators, first with primary charge Dextrinated Lead Azide RD-1352 and second Lead Styphnate RD-1303 with same PETN as intermediate and secondary charge. Primary and intermediate charge were loaded at same pressure of 30 M pa with secondary charge at 120 M pa. Five detonators were tested for each primary charge.

Table 5.6 Primary charge nature vs. Function time

Primary charge	Loading Pressure (MPa)	Function Time (µ sec)					Ave (µ sec)
Sample Number		1	2	3	4	5	
LS	30	61.0	56.7	56.0	59.0	62.3	59.0
DLA	30	22.6	30.2	24.3	29.0	26.1	26.4

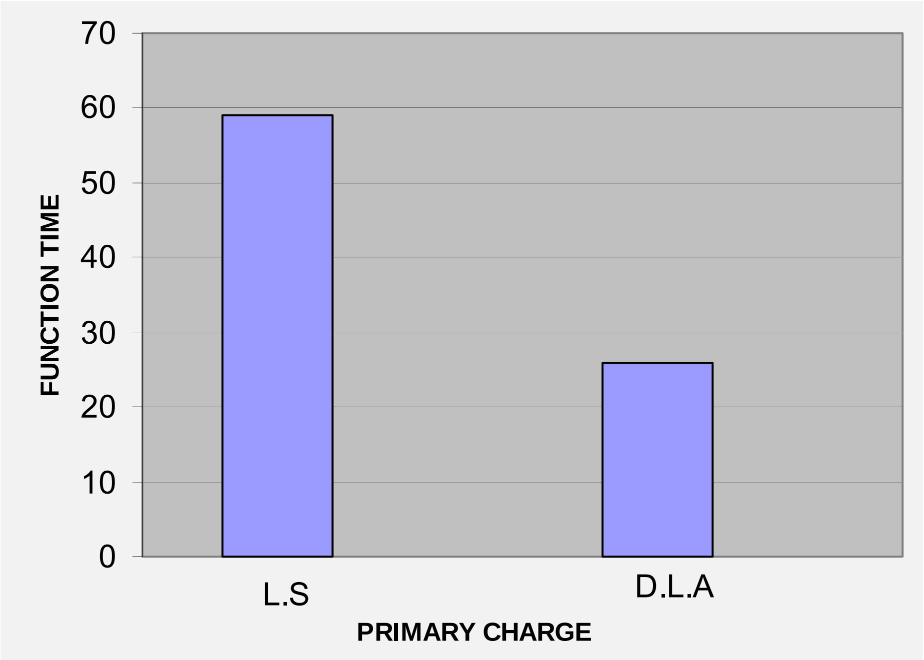

Figure 5.4 Function time comparisons with two different primary charges

Reaction rate of the charge material depends on its characteristics. If the heat is produced by the reaction faster than it can be transferred away, then the temperature of the reacting material must increase. Hence reaction rate increases. The heat transfer rate depends on temperature as well as thermal conductivity, heat capacity, and density.

Growth of reaction in Lead Styphnate is very slow. Dextrinated Lead Azide makes the transition from burning to detonation quite suddenly.

This behavior of the initiating charges was reflected in the test results shown in the table no.5.6. Longer function time was recorded with Lead Styphnate than DLA at the same load pressure.

CONCLUSION

From the present work it has been observed that load pressure and nature of primary charge clearly affect the function time of the detonator.

When the load pressure increases on the primary charge filled on the flushed wire-bridge detonator, function time and its dispersion decrease with increase in primary charge load pressure. Dextrinated Lead Azide becomes insensitive at 80 MPa whereas Service Lead Azide remains sensitive even at 300 MPa. Dextrinated Lead Azide, depending on its characteristics, has function time shorter than the function time of the Lead Styphnate.

Keeping other parameters constant, high load pressure can be used to decrease function time. Decrease in dispersion with increase in load pressure can be used to make function time more precise and reproducible. Decrease in sensitivity with primary charge load pressure also improves the detonator's no ignition capability at safe current. These two aspects can be used in the design of detonators to meet specific requirements.

SUGGESTIONS FOR FUTURE WORK

The present project involves the comparative study for the detonator function time using two different primary charges, viz DLA and LS. It is suggested that function time may be determined and compared with other primary charges like mercury fulminate, tetrazene and also different pyrotechnics initiating compositions for initiators.

Charge density increases with load pressure. It has been observed that threshold firing energy of the detonator increases with increase in primary charge density. A comparison study may be made between increase in load pressure of primary charge DLA and variation in threshold firing energy.

It has been seen that DLA became insensitive at 80 MPa whereas SLA remained sensitive even at 300 MPa and initiated successfully through 5 uf capacitor charged up to 24 V. So, work may be carried out to determine the minimum loading pressure which makes the detonator insensitive.

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