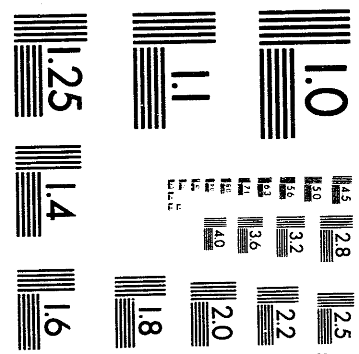
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SAND93-1873C
Unlimited Release
Printed January 1994

Distribution
Category UC-742

Optical Ordnance System For Use In Explosive Ordnance Disposal Activities*

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ABSTRACT

A portable hand-held solid state rod laser system and an optically-ignited detonator have been developed for use in explosive ordnance disposal (EOD) activities. Laser prototypes from Whittaker Ordnance and Universal Propulsion have been tested and evaluated . The optical detonator contains 2-(5 cyanotetrazolato) pentaamine cobalt III perchlorate (CP) as the DDT column and the explosive Octahydro - 1,3,5,7 - tetranitro - 1,3,5,7 - tetrazocine (HMX) as the output charge. The laser is designed to have an output of 150 mJ in a 500 microsecond pulse. This output allows firing through 2000 meters of optical fiber. The detonator can also be ignited with a portable laser diode source through a shorter length of fiber.

1.0 INTRODUCTION

Sandia National Laboratories has been actively pursuing the development of optically ignited explosive subsystems for several years concentrating on developing the technology through experiment[1-3] and numerical modeling of optical ignition.[4,5] Several other references dealing with various aspects of optical ordnance development are also available in the literature.[6-10] Our primary motivation for this development effort is one of safety, specifically reducing the potential of device premature that can occur with a low energy electrically ignited explosive device (EED). Using laser ignition of the energetic material provides the opportunity to remove the bridgewire and electrically conductive pins from the charge cavity, thus isolating the explosive from stray electrical ignition sources such as electrostatic discharge (ESD) or electromagnetic radiation (EMR). The insensitivity of the explosive devices to stray ignition sources allows the use of these ordnance systems in environments where EED use is a safety risk.

The Office of Special Technologies under the EOD/LIC program directed the development of a portable hand-held solid state rod laser system and an optically-ignited detonator to be used as a replacement of electric blasting caps for initiating Comp C-4 explosive or detonation cord in explosive ordnance disposal (EOD) activities. The prototype systems that have been tested are discussed in this paper. Laser prototypes were procured from both Whittaker Ordnance (now Quantic) and Universal Propulsion Company and tests were conducted at Sandia National Laboratories. An optical detonator was designed at Sandia National Laboratories and built by Pacific Scientific - Energy Dynamics Division formerly Unidynamics in Phoenix (UPI).

2.0 THEORY OF OPERATION

The intent of the optical firing system is to provide the same functional output performance of an

*This work was sponsored by the Office of Special Technologies under funding documents NO464A92WR07053 and NO464A91WR10380 and supported by the United States Department of Energy under Contracts DE-ACO4-76DP00789 and DE-ACO4-94AL85000.

electrically fired blasting cap without the use of primary explosives. Electrical detonation systems use current to heat a bridgewire which in turn heats an explosive powder to its auto-ignition temperature through conduction. In contrast, an optical system uses light energy from a laser source that is absorbed by the powder, thus raising its temperature to the auto-ignition temperature. The primary advantage of optical ignition is that there are no electrically conductive bridgewires and pins in direct contact with the explosive powder. This removes the potential electrostatic discharge pathways and eliminates premature initiations which can be caused by stray electrical signals. This is illustrated by the comparison of the electrically and optically ignited ordnance systems shown in Figure 1.

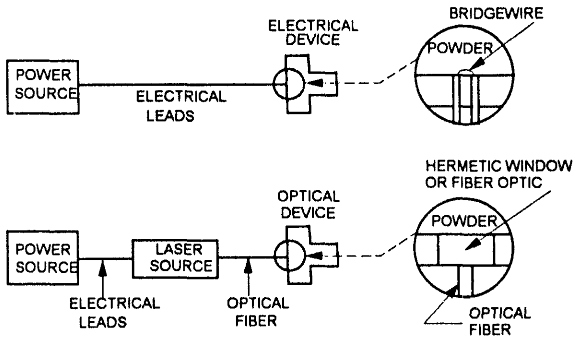

Figure 1. Comparison of electrically and optically ignited ordnance systems.

3.0 SYSTEM DESCRIPTION

The optical system is intended to be an additional tool for EOD applications which provides a HERO (Hazards of Electromagnetic Radiation to Ordnance) safe system with a detonation output sufficient to directly initiate Comp C-4 or detonation cord without the use of primary explosives such as Lead Azide. The system contains an optical detonator, a portable, battery operated laser, and optical fiber to couple the laser output to the detonator. Each part of the system will be discussed individually.

3.1 Detonator Description

A drawing of the detonator design is shown in Figure 2. The detonator relies upon the deflagration to detonation transition or DDT. The detonator contains approximately 90 mg of 2-(5-cyanotetrazolato) pentaamine cobalt III perchlorate or CP (see Figure 3 for chemical structure) for the DDT column and 1 g of HMX for the output charge. The detonator wall around the HMX output charge is thin in order to minimize the attenuation of the shock produced by the detonation of the HMX. The detonator incorporates threads that will accept a standard SMA 906 optical connector. The connector positions the optical fiber in contact with a sapphire window as shown in Figure 2. This optical interface and the use of optical fibers instead of electrical wires completely de-couples stray electrical sources from the detonator by removing any electrical path to the explosive.

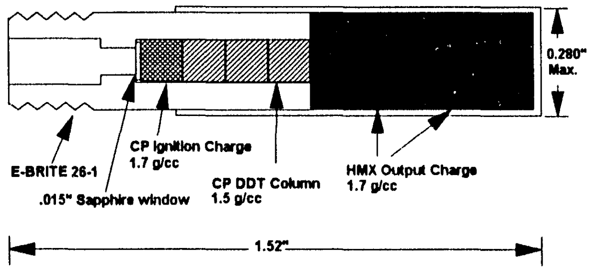

Figure 2. SMA compatible optical detonator with doped CP ignition charge, undoped CP DDT column and a HMX output charge.

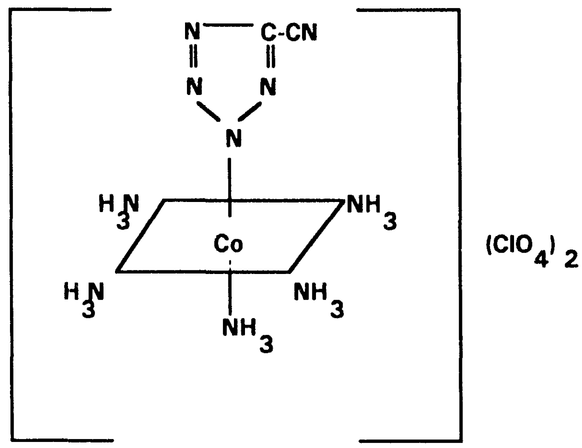

Figure 3. 2-(5-cyanotetrazolato) pentaamine cobalt III perchlorate or CP.

The optical ignition of explosives depends on the optical power delivered and the energy absorbed by the explosive. This dependence is important at low power as shown Figure 4.

At low power, it is necessary to dope some explosives with other materials such as carbon black or graphite in order to increase their absorptance of the optical energy and thus lower their ignition threshold. We have chosen to use CP doped with 1% carbon black so that these detonators can be fired from lower power laser sources such as laser diodes. At high powers, such as that provided by the Navy EOD system, a minimum energy must be delivered to the explosive in order for it to ignite. As seen in Figure 4, this minimum energy for doped CP is on the order of 0.25 mJ. The Navy EOD system uses a solid state rod laser capable of delivering 100 to 200 mJ of optical energy in a fraction of a millisecond. Explosive doping is not required in this detonator when utilizing the high power rod laser but was implemented so that the detonator could be used for a wide range of applications.

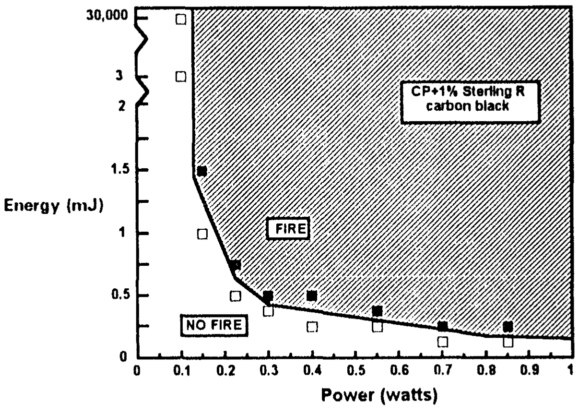

Figure 4. Optical ignition threshold for doped CP at low laser powers.

Successful ignition and function of the optical detonator has been achieved with both portable solid state rod laser systems powered by a 9 V supply and by a portable semiconductor laser diode system powered by five 9 V batteries (45 V total). The operational goals of the detonation system require the use of long optical fiber lengths (up to 2000 m) which may have optical attenuation or loss near 90 percent with fibers that have 4 - 5 dB/km loss. Fibers with higher loss per kilometer will enhance the optical attenuation problem. The portable laser diode is capable of delivering 2 W of optical power, well within the ignition requirements, but insufficient to overcome the cable losses in 2000 m of optical cable. For this reason, the EOD system uses solid state rods for the optical energy supply which are discussed in the next section.

3.2 Solid State Rod Laser

Two laser firing unit designs have been built by Whittaker Ordnance (now Quantic) and by Universal Propulsion Company in Phoenix. The Whittaker design was the first generation prototype followed by the second generation prototype design from Universal Propulsion. Both systems have been shown to be effective at igniting the optical detonator through 1000 meters of optical fiber. Both laser designs are discussed below.

The first laser firing unit for the Navy EOD laser ordnance system was built by Whittaker Ordnance and was designed to be portable, rugged, water-proof during transport, and battery operated. The laser unit contains a 9-volt battery which supplies voltage to a DC/DC converter to step up the voltage to approximately 500 volts. This voltage charges the 300 μf capacitor which supplies current to the flash lamps. The functioning of the flashlamps excites the laser rod material, Nd doped YAG, and causes the laser to function. The system is designed to deliver between 100 and 200 mJ of optical energy during a 500 microsecond pulse. This exceeds the energy required for the ignition of the detonator by at least 2 orders of magnitude. The laser output is coupled into a 200 μm optical fiber which can be connected to the laser firing unit using the SMA 905 connector port on the top of the laser.

The laser can be easily transported in the field. It is contained in a cylindrical container which is approximately 3.5 inches in diameter and 6 inches tall. The package weighs about 2 pounds. The laser is not eye safe and care must be taken to properly protect the operator and any casuals from exposure to the beam. Laser safety glasses with an optical density of 4.6 or greater are required for personnel within 10 feet or 3 meters of the laser or the output end of a fiber when it is coupled to the laser. During operations, one person maintains positive control of the laser and the optical detonators. It is the responsibility of that person to assure that all personnel within the exposure radius of 3 meters have the proper eye protection. Once this is verified, the laser can be armed by depressing the arm button on the top of the laser firing unit. After 10 to 30 seconds, the fire light will begin to blink. The laser can then be fired by depressing the fire button. The optical fiber can then be disconnected from the laser and the protective cover placed back on the optical port on the laser.

The second generation laser was designed and built by Universal Propulsion Company. It improved upon the packaging, specifically with respect to environmental protection, and maintained a comparable laser output to the Whittaker laser. This laser uses either six 1.5 V AA batteries or three 3 V AA batteries to power the laser with a 9 V supply. The 9 V supply is stepped up to 360 V to charge a 200 µf capacitor. The body of the laser is more rugged and environmentally sealed. The housing is similar to a flashlight housing and is 10.1 inches long and 2.75 inches in diameter. The laser weighs 2.1 pounds. Operation of the laser is similar to that of the Whittaker design. The design utilizes a rotary arm/fire switch located in the rear of the laser housing. The laser delivers 200 - 300 mJ optical energy in a 200 µsec pulse. The optical energy is coupled into a 200 µm fiber using a press fit SMA 906 connector which attaches to the front of the laser housing.

3.3 Optical Fiber and Connections

The optical energy from the laser is coupled to the optical detonator with the use of optical fiber. The fiber contains a core glass and either a glass or plastic cladding depending on the manufacturer. The mismatch of the index of refraction of the core and cladding is such that all of the optical energy in the core glass is internally reflected by the cladding in a process known as total internal reflectance. Each optical fiber is described by a size and numerical aperture (NA). The size of the fiber is determined by the core glass diameter. The Navy EOD system uses 200 µm fiber and could easily be adapted to larger diameters such as 400 µm. The NA of the fiber describes the acceptance angle of the light that can be coupled into the fiber such that the light in the fiber does not exceed the critical angle and is totally internally reflected. The core and cladding are coated with an organic buffer to add strength. Additional layers of plastic and other strength members including Kevlar are used in the optical fiber cable to give it additional strength. The overall cable diameter can vary depending upon the jacketing and strength member materials but is on the order of 0.125 inches.

The optical fiber is relatively durable, however it can be broken. Care should be taken to avoid sharp bends less than 0.5 inch radius. Using a visible light source which should be eye safe, the operator can check for breaks in the optical cable by shining the light through the fiber. During system setup, the light can be transmitted through the fiber to verify continuity. If the light does not appear at the other end, then there is a break in the fiber cable. Only an eye safe, low power, light source should be used for checking fiber continuity. The fiber continuity cannot be checked by the laser firing unit as it is not eye safe, and the laser light is invisible to the human eye.

Connections to optical fibers can be made with standard optical connectors. This procedure can be done in the field if required but is easier if done ahead of time. The polish on the optical fiber is important on the laser end. The polish on the detonator end is not as critical and a simple cleave of the fiber is sufficient. During explosive shots, the last portion of the optical fiber is destroyed. Therefore, it is recommended that optical cable jumpers be prepared ahead of time and used in the field to minimize the number of connectors that are made in the field.

4.0 SUMMARY

The optical ordnance system utilizes laser light energy to ignite an explosive powder contained in a detonator. The detonator is HERO safe and produces a detonation output sufficient to detonate Comp C-4 or detonation cord. The detonator does not contain primary explosives. The laser is portable and powered by batteries. The optical energy from the laser is coupled into standard optical fiber which is connected to the detonator. Jumpers are used to minimize the number of optical fiber terminations that must be made in the field with multiple shots. The system has been shown to be effective at detonating Comp C-4 through 1000 meters of optical fiber.

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