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Author(s): A. C. Munger, K. A. Thomas, J. E. Kennedy, A. A. Akinci, H. L. Mallett

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LASER DETONATOR DEVELOPMENT FOR TEST-FIRING APPLICATIONS

A. C. Munger, K. A. Thomas, J. E. Kennedy, A. A. Akinci, H. L. Mallett
Los Alamos National Laboratory, Los Alamos, NM 87545, USA

ABSTRACT

Los Alamos National Laboratory has historically fielded two types of electro-explosive detonators. The exploding-bridgewire detonator (EBW) has an exploding wire as the initiating element, a low-density transfer charge and a high-density output pellet. The slapper detonator, or exploding-foil initiator (EFI), utilizes an exploding foil to drive a flying plate element into a high-density output pellet. The last twenty years has seen various research and development activities from many laboratories and manufacturing facilities around the world to develop laser-driven analogs of these devices, but to our knowledge none of those is in general use. Los Alamos is currently committed to design and manufacture a laser analog to the long-standing, generic, general-purpose SE-1 EBW detonator, which is intended to provide increased safety in large-scale test-firing operations. This paper will discuss the major design parameters of this laser detonator and present some preliminary testing results.

Introduction

The principal motivation for use of high-power laser detonators is to gain safety against electrical hazards of any kind. This includes safety in the face of lightning or less powerful electrostatic discharges from charged conductive equipment or a human body. In the class of detonators we shall discuss, high power is introduced into the detonator through an optical fiber. There are no plausible ways in which electrical energy can couple into the detonator to pose the threat of unintended detonation. Since Los Alamos is located in the Jemez Mountains of New Mexico and that area receives the second largest number of lightning strikes in the U.S. during the summer monsoon season, our Laboratory has a motivation to develop a solution for safe explosive firing operations under conditions of high electric field in the atmosphere. There are real safety and thus operational advantages to a design that does not provide an electrical path to the energetic material.

A study on the laser analog of the EBW detonator was presented at the 28th IPS Seminar[4]. Our approach now is to design a device of that kind – the "laser EBW" -- that may be attractive for use at large-scale test-firing sites. The laser EBW has the advantage of operating at laser power requirements that can be transmitted through pure-silica optical fibers, with a margin for reliability of the fiber. In addition, our experience to date indicates that the reliability of the explosive train of the laser EBW is not dependent upon the intensity profile of the laser beam. The suitability of a given laser beam intensity profile is dependent only on the question of whether the fiber is able to reliably transmit the beam. Another potential problem for high-power optical systems is the lack of cleanliness and the moisture that may exist in an operational environment. This paper, however, addresses mainly the explosive design issues of the laser EBW detonator rather than the laser-beam intensity profile and optical fiber issues.

The current device used in many of our experimental tests is the SE-1 EBW detonator. There is therefore a great desire to make available to test-site operators a device that is very similar to the electrically fired SE-1 detonator that they currently use, but which has the inherent increased safety of a laser-fired detonator. The ER-459 detonator is being designed to be that device.

Discussion

The SE-1 EBW detonator is an old design but satisfies most of an experimenter's needs in terms of output. The ER-459 uses many of the same hardware and explosive components as that SE-1. The ER459 uses the sane confinement sleeve and output pellet and has an initial pressing of low-density PETN that is identical in mass and density to that in the SE-1. The plastic plug and electrical feed through are replaced with a brass SMA adapter. A 0.5-mm-thick fused silica plate with titanium plated onto the low-density-PETN side of the plate is placed on top of the SMA adapter body and is trapped between the adapter and the confinement sleeve. The ER-459 laser-fired detonator is shown in figure 1.

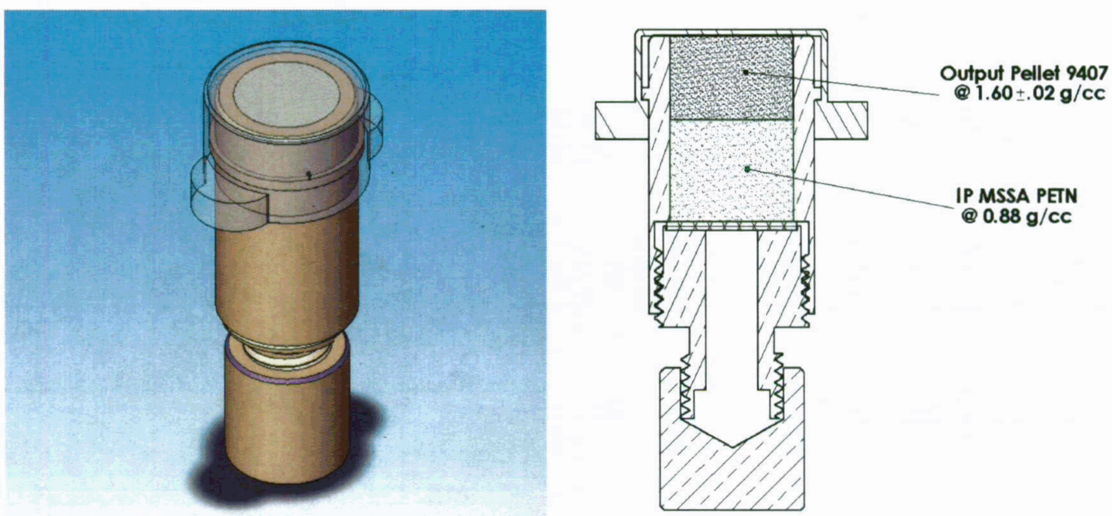

Figure 1 ER-459 Laser Detonator

Kennedy et al.[4] reported a minimum threshold firing energy of 9.5 mJ with 0.90 g/cm^3 medium-specific-surface-area PETN (denoted MSSA PETN, about 12,000 cm^2/g). The laser pulse duration was 15 ns and the laser spot size was 977-μm in diameter on a 2350-A-thick Ti film in those experiments. Our current design has more favorable laser power-density conditions for purposes of PETN initiation, i.e., 10-ns pulse duration and an illuminated spot size of 650 mm. It is anticipated that these conditions may produce a lower threshold firing energy, but those experiments have not yet been performed.

The laser firing source is a Nd:YAG or GSGG rod laser that is pumped by an electrically driven flash tube and is actively Q-switched. The output pulse is at 1064 (or 0161) nm, and the full-width/half-max pulse duration is 10 ns. The laser capacity is 100 mJ, and we estimate that operational firing energy will be 20 mJ for reliable detonator operation. The laser is set up with beam-splitters that provide multiple output beams, so that more than one detonator may be fired with the same laser pulse. A breadboard assembly that we are currently using is about the size of a cigar box.

At an operational firing energy of 20 mJ, the average power level is almost 2 MW, and the average power density in the 400-μm-core fiber that delivers the power to the detonator that is about 1.6 GW/cm^2. This level of power density is well within the capability of fused-silica fiber, as shown by the work of Setchell and Berry.[2]

Previous experience at Los Alamos has been consistent with that of Renlund et al[1] of Sandia, who found that a minimal threshold firing energy of about 20 mJ. The lowest threshold value in work at LANL has been 9 mJ. Testing to date with the ER-459 detonator has been limited to "hard-fire" at operational conditions

All tests were done using the Thompson CCD streak camera with a total sweep-time of approximately 600ns and timing marks marking every 20ns. The Detonators were fired using the GSGG Kansas City Laser (Serial Number 001) at an average energy of 24.1mJ. The detonator design incorporated a mating SMA connector to facilitate the attachment of the 400μm fiber. All thirty shots were successfully fired with streak data, laser pulse width, and timing data successfully captured.

The testing results reported here are from a lot of ER-459 Detonators that were built using technicians and the detonator assembly people at Los Alamos. Hardware sufficient to produce 30 detonators was procured and inspected to the design requirements. The fabrication of these units was conducted in "near" manufacturing conditions. This was done to access our ability to reproducibly build the detonator.

Results

All tests were done using the Thompson CCD streak camera with a total sweep-time of approximately 600ns and timing marks marking every 20ns. The Detonators were fired using the GSGG Kansas City Laser (Serial Number 001) at an average energy of 24.1mJ. The detonator design incorporated a mating SMA connector to facilitate the attachment of the 400μm fiber. All thirty shots were successfully fired with streak data, laser pulse width, and timing data successfully captured.

The two designs differ only the initiation source and IP powder. The electrically fired SE-1-31 IP was a coarse PETN powder while the ER459 was loaded with a MSSA PETN powder. The basic SE-1 design dates back to the late 50's and the understanding of the particle size effect on ignition was just being studied. The ER-459 is designed with a smaller particle size powder to facilitate ignition from the laser beam. The SE-1 was fired at 2500V with a 6.2 μFarad capacitor. The ER459 was fired at 25 mJ.

SE-1 Properties	
Explosive	PBX9407
Pellet Diameter	0.299" (7.62 mm)
Explosive Stack Up	0.450" (11.43 mm)
Initial Pressing (IP) Height	0.203" (5.156 mm)
IP Density	0.88 g/cc
Output Pellet Density	1.60 g/cc

Below are shown two streak records one each from an SE-1 and one from an ER-459 laser detonator.

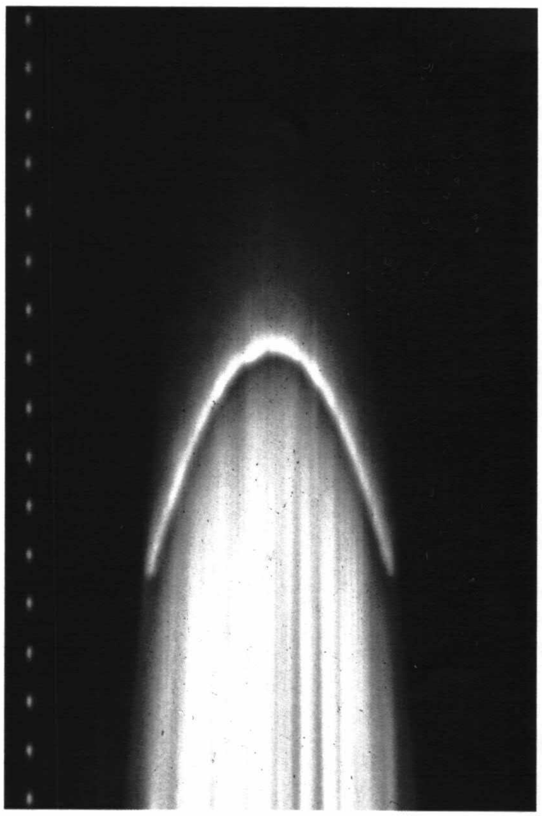

Figure 2 Output of the ER-459 Laser detonator

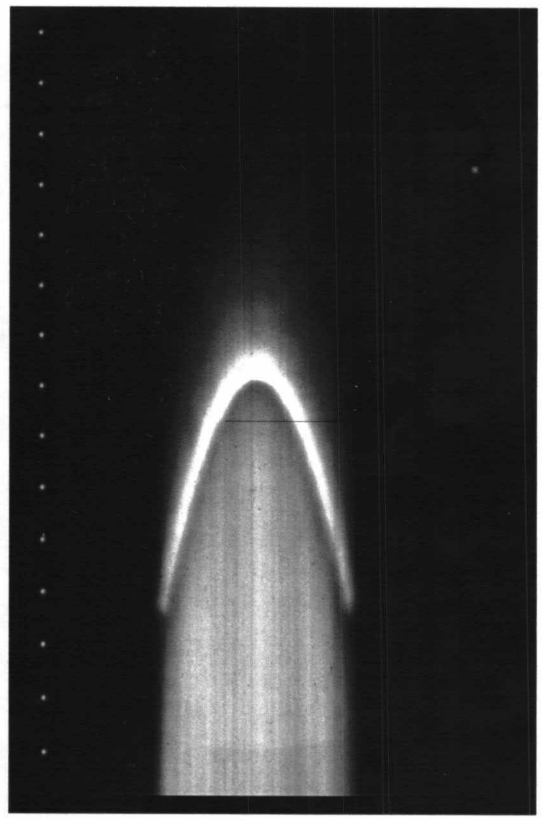

Figure 3 Output of the SE-1 detonator

The methods for collecting the data were the same. The streak camera was used to record the breakout of the images (Timing Marks on the Camera were 20 ns). The analysis was done the Matlab version of ICON (MICON).

For the ER459, breakout time was measured from the start of rise in the laser pulse to the breakout of the detonation wave. On the streak camera image this corresponds to the darkness that occurs immediately after initial light. There is a discrepancy between the measurements of total time between the two designs because the SE-1 was measured from the current burst instead of the start of current. In both cases, error was introduced into this measurement because the firing pulse scope was only sampling at 10 ns for the ER459 and 5ns for the SE-1.

The average time on the SE-1 was 2516 ns. These numbers were determined from only 5 shots. The difference between min/max in 5 shots was 42 ns. The average time on the ER459 was 2186 ns with a standard deviation similar to the SE-1. The function time of the ER459 was 330 ns faster than the SE-1-31.

Some of the following issues may have contributed to error the measurements. There is about 3-5 ns error in measuring the location of the center of the fiducial on the image. The sampling rate on the scope was 10 ns, which therefore makes it difficult to determine location of the rising pulses. There is also jitter from firing the laser itself.

Conclusions

The success of the testing of the 30 units in this build leads us to believe that we have a manufacturable design for the detonator and that it can be incorporated into any test that now would use a SE-1. A build of about 60 more detonators is now underway. This group will be used to show reproducibility of the manufacturing process and to accurately determine the threshold energy required for the detonator.

The value of determining the threshold firing energy required under our current firing conditions is to establish the margin for reliability that we will have if we fire operationally at 20-25 mJ. Another is to determine whether our current 2500-A-thick Ti film is optimal for this application. We intend to experiment also with 3000-A and 3500-A films. We expect that the optimal film thickness will be between 2350 A and 4000 A, because Nagayama et al.[3] showed that 4000-A films were less effective than thinner films in low-density PETN initiation experiments quite similar to our own. The data appear to indicate that firing energy is reduced by use of a thicker titanium film, as long as the entire film thickness is ablated by the laser pulse. In Nagayama's experiments, their 4000-A-thick film was not completely ablated (shards were driven into the PETN bed, as observed by flash radiography) and the initiation performance suffered, probably as a result of that.

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