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Nd:YAG Breech Mounted Laser Igniter

Christopher R. Hardy, Michael J. Myers, John D. Myers, Robert L. Gadson
Kigre, Inc., 100 Marshland Rd, Hilton Head Island, SC 29926, USA
Kigre@aol.com, Ph: 843-681-5800, Fax: 843-681-4559

Joseph Leone, Josiah W. Fay
US ARMY ARDEC, Bldg. 62N
Picatinny Arsenal, NJ 07806-5000
jleone@pica.army.mil, Ph: 973-724-6347, Fax: 973-724-6481

Kevin Boyd
US Army Research Laboratory
Advanced Weapons Concepts Branch
AMSRL-WM-WF, Bldg #1121
Aberdeen Proving Ground, Maryland 21005-5066, USA
jkboyd@arl.mil, Ph: 410-278-2505. Fax: 410-278-8829

Abstract

Nd:YAG lasers have been successfully used to demonstrate laser ignition of howitzer propellant charges including bag, stick, and the Modular Artillery Charge System (MACS). Breech Mount Laser Ignition Systems (BMLIS) have been designed, installed and tested on many artillery systems, including the US Army's M109A6 Paladin, M198, M777 Light Weight, Crusader, and Non-Line-of-Sight Cannon (NLOS-C). The NLOS-C incorporates advanced weapon technologies, to include a BMLIS. United Defense's Armament Systems Division has recently designed and built a NLOS-C System Demonstrator that uses a BMLIS that incorporates Kigre's patented[i] square pulse technology. NLOS-C is one of the weapon systems being developed for use with the US Army's "systems of systems" Future Combat System (FCS), Manned Ground Vehicles (MGV) program, and is currently undergoing development testing at Yuma Proving Grounds. In this paper we discuss many technical aspects of an artillery laser ignition system and present BMLIS test data obtained from actual gun firings conducted with a number of different US Army howitzer platforms.

Key Words: Laser Ignition, Pulsed Nd:YAG laser, Breech Mounted Laser, Laser Ordnance Ignition

Introduction

Laser ignition of standard charges has been considered because it eliminates primers, increases the firing rate potential, and dramatically increases operator safety. Eliminating brass primer cartridges and lead-containing primers reduces the logistical burden and can result in long-lasting environmental benefits. This paper describes a ruggedized breech mounted laser ignition system that provides both durability and reliability in the extremely harsh environment that the Army's howitzers are subjected to. This approach will dramatically improve existing ignition system's Mean Time Between Failures (MTBF).

Technical Approach

Laser ignition and laser pyrotechnic initiation technology is a relatively mature field and basic engineering is not required[ii]. Safety theme validation[iii] is a primary focus now and continued emphasis has been on system reliability. Various types of laser systems were initially considered **[Table 1]** including Solid-State (Nd:YAG, Nd:Glass), Diode (GaAlAs), Gas (CO_2, Excimer), and Liquid (R-6G)[iv]. Size and complexity limitations reduced these choices to two: Solid-State lamp and Diode based laser systems.

LASER TYPE	ADVANTAGES	DISADVANTAGES
Lamp Pumped	Low Divergence High Peak Power Breech Mountable	Requires High Voltage Driver
Direct Diode Pumped	High Efficiency Low Voltage Driver Breech Mountable	High Divergence Low Brightness Beam

Table 1

A diode laser's high divergence requires external beam conditioning optics that may severely impact the ability to design in the required ruggedness of the laser delivery system. In addition, direct diode laser pumping typically employs a fiber-optic based system to deliver the laser energy from a remote location to the propellant. Various fiber optic approaches have been tested, but very few have been able to demonstrate that they can survive repeated gun firings when used with large caliber weapons. Use of a fiber optic cable to couple a remote laser to the gun dramatically reduces the standoff distance at which a charge can be ignited. When the beam is projected through the fiber optic, the numerical aperture of the fiber is filled, decreasing the beam divergence.

Since the lamp pumped breech-mounted laser design does not require use of fiber optics, the laser power density and beam divergence properties remain intact. **Figure 1** shows that the confocal parameter[v] of the breech-mounted laser is approximately five times longer than that of the fiber-coupled laser[vi]. Therefore, a breech-mounted laser design/approach allows for a five times greater error in charge positioning than that of a fiber-coupled laser design/approach.

Different types/variations of flashlamp pumped solid-state lasers were considered as shown in **Table 2**. To eliminate the burden of forced liquid or air-cooling, the breech-mounted laser relies on conduction cooling. Therefore, the laser material (refer to "Laser Type" column in Table 2) must exhibit adequate thermal transfer characteristics to insure good beam quality and output stability. The material should have a relatively high conversion efficiency to reduce the amount of pump energy, and therefore heat, put into the system. The laser material must also have extremely high strength to prevent fractures or other stress related damage.

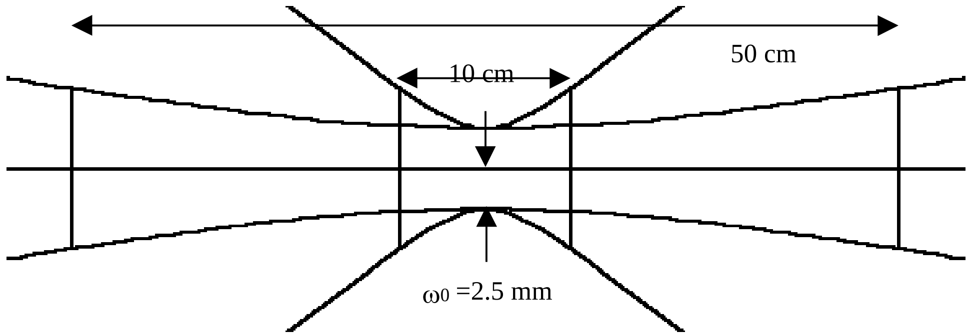


Illustration of the confocal parameter for the fiber coupled laser (10 cm) and the direct breech mounted laser (50 cm). The confocal parameter is distance between the points at each side of the waist where the beam diameter is √2 times the waist. These points are where the power density drops to ½ that at the waist. The divergence angle of the fiber coupled laser is 24 mr (600 μm fiber, 0.2 NA) and the divergence of the breech mounted laser is 5 mr. Both laser beams have a waist diameter of 5 mm.

Figure 1

LASER TYPE	WAVELENGTH	EFFICIENCY	COMMENTS
Alexandrite	755 nm	3%	High Thermal Equilibrium Temp
Er:Glass	1535 nm	3%	Poor Thermal Characteristics
Er:YAG	2940 nm	2%	Low Efficiency, Special IR Optics
Ho:YAG	2130 nm	2%	Low Efficiency, Special IR Optics
Nd:Glass	1053 nm	4%	Poor Thermal Characteristics
Nd,Cr:GSGG	1061 nm	7%	Poor Thermal Characteristics
Nd:YAG	1064 nm	4%	Rugged, Mature Technology
Nd:YLF	1047 nm	3%	Brittle
Ruby	693 nm	1%	Very Low Efficiency

Table 2

Considering all of the above factors, a Nd:YAG laser material was chosen. Output energy specifications were based on the US Army's MACS propellant design and the expected worst case energy losses attributed to beam divergence. Considerations were also included for other potential obstructions that could be encountered along the laser beam/optical path, before reaching the MACS black powder base pad. Propellant burn qualities and burn rates were evaluated using various laser pulsewidths and energy variations.

After extensive testing, the ideal pulse duration was determined for reliable propellant ignition. Standard flashlamp pumped lasers typically use a Gaussian R-L-C network to flash the lamp. To generate the ideal pulse duration, large inductors must be used that significantly reduce the pumping efficiency. The large inductors also increase weight and size of the Pulse Forming Network (PFN).

Kigre's patented[vii] square pulse technology is a perfect match for the breech mounted laser ignition system. The solid-state square pulse driver eliminates the high I^2R loss of the inductive element and reduces overall operating currents and voltages. The square pulse system also delivers a relatively constant current to the flashlamp allowing it to reach a stable color temperature[viii], and therefore a stable pump output.

The flashlamp based laser system generates the high peak powers needed, allowing the laser to help overcome optical path losses, moist charges, and other conditions that may be detrimental for a successful ignition. The increased energy also allows for the potential use of other propellant materials which may exhibit higher laser pulse energy thresholds.

Since the various howitzer cannons use similar propellant materials, the per-shot energy difference between applications is relatively small. The determining factor in laser design was therefore based on repetition rates as shown in **Table 3**.

Program	Description	Max Firing Rate	Charge Type
FCS NLOS-C	Self-Propelled Fully Auto Non-Line-of Sight Cannon 20-ton	10 rounds per minute	MACS (Zones 1-4)
Paladin	Self-Propelled Howitzer 30-ton	8 rounds per minute	M3A1, M4A2, M119A1, M203A1, MACS (Zones1-5)
M777	Towed 155mm Howitzer, 9000 lbs.	4 rounds per minute	M3A1, M4A2, M119A1, M203A1, MACS (Zones1-5)
M198	Towed 155mm Howitzer, 16000 lbs.	4 rounds per minute	M3A1, M4A2, M119A1, M203A1, MACS (Zones1-5)
Crusader	Self-Propelled Howitzer 40-ton	10 rounds per minute	MACS (Zones 1-6)
FDSWS	Towed 155mm Howitzer, 5000 lbs.	5-8 rounds per minute	M3A1, M4A2, M119A1, MACS (Zones1-4)

Table 3

Applying the Output Coupler (OC) and High Reflective (HR) optics directly to the rod ends eliminated the problems associated with resonator alignment. A prototype breech mounted laser using Kigre's standard FC series pump chamber was developed under an SBIR Phase II contract with ARL[ix]. This prototype laser was attached perpendicular to the gun barrel (firing) axis and used a prism to turn the beam 90^o as shown in **Figure 2**.

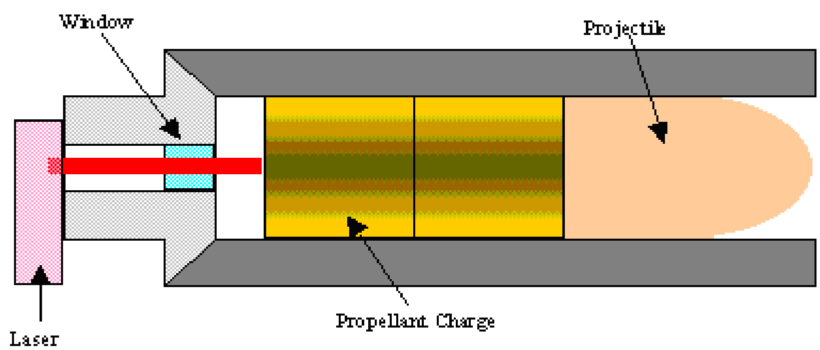


Figure 2

Kigre's standard FC series pump chamber performed well, but did show a small amount of damage due to the high shock environment. They were also designed to be water cooled, and could not maintain output stability at high repetition rates as shown in **Figure 3.**

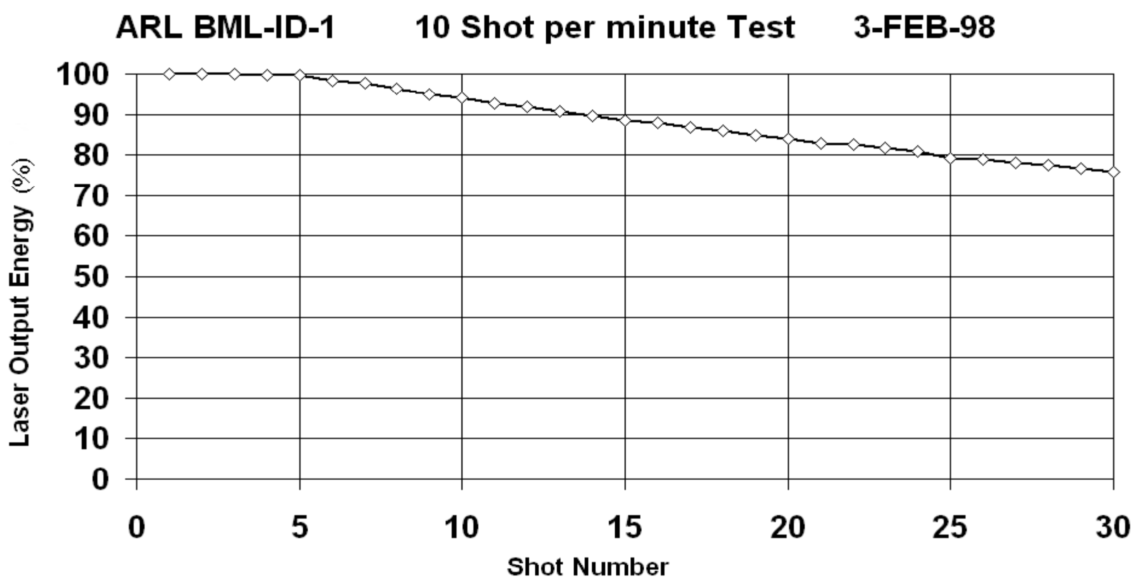
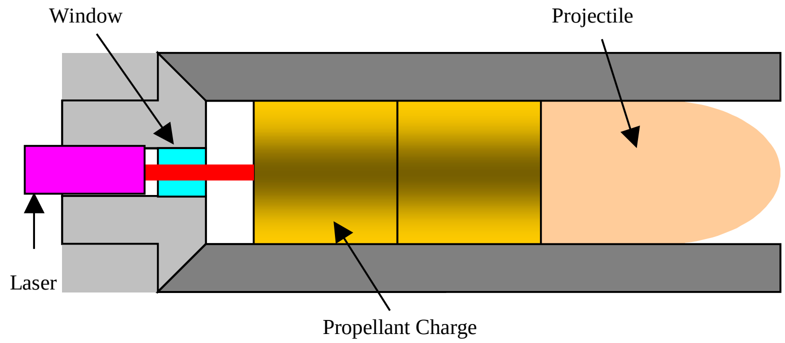


Figure 3

Under a Phase III SBIR contract[x], Kigre revised the FC design to drastically improve the survivability under high shock loads. This new design also improved the thermal transfer characteristics of the laser. The laser was designed to fire along the same axis as the barrel, eliminating the turning optic as shown in **Figure 4**, eliminating the need to turn the optics.



"Inline" Direct Coupled Laser Igniter

Figure 4

Experimental Results

At 4 Pulses Per Minute (PPM; also known as rounds per minute), a single flashlamp pumped laser worked extremely well. The laser's output energy and location were quite stable as shown in **Figure 5**.

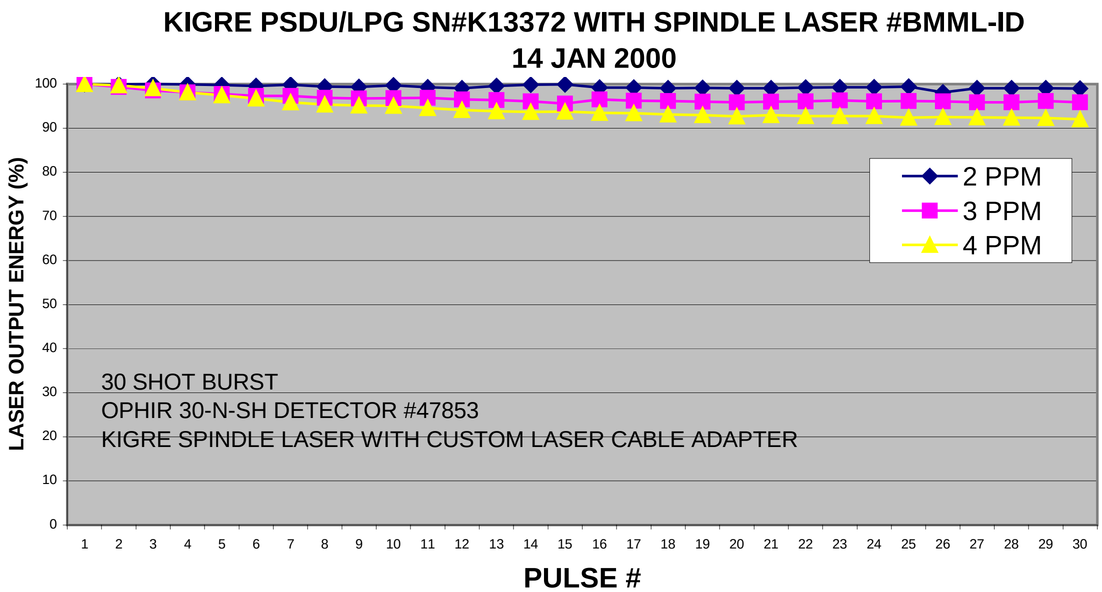


Figure 5

However, at firing rates above 6 pulses per minute, with the single lamp design, the heating effect actually caused the rod to bend slightly. Although the output energy was stable, the rod movement altered the beam's path which resulted in significant reduced energy, resulting from "beam walk", delivered to the propellant. The beam-walk issue was resolved when Kigre incorporated a dual flashlamp pumping approach. The two lamps were symmetrically placed around the rod to provide a uniform pumping pattern. Figure 6 shows output data of Kigre's dual flashlamp Breech Mounted Laser (BML).

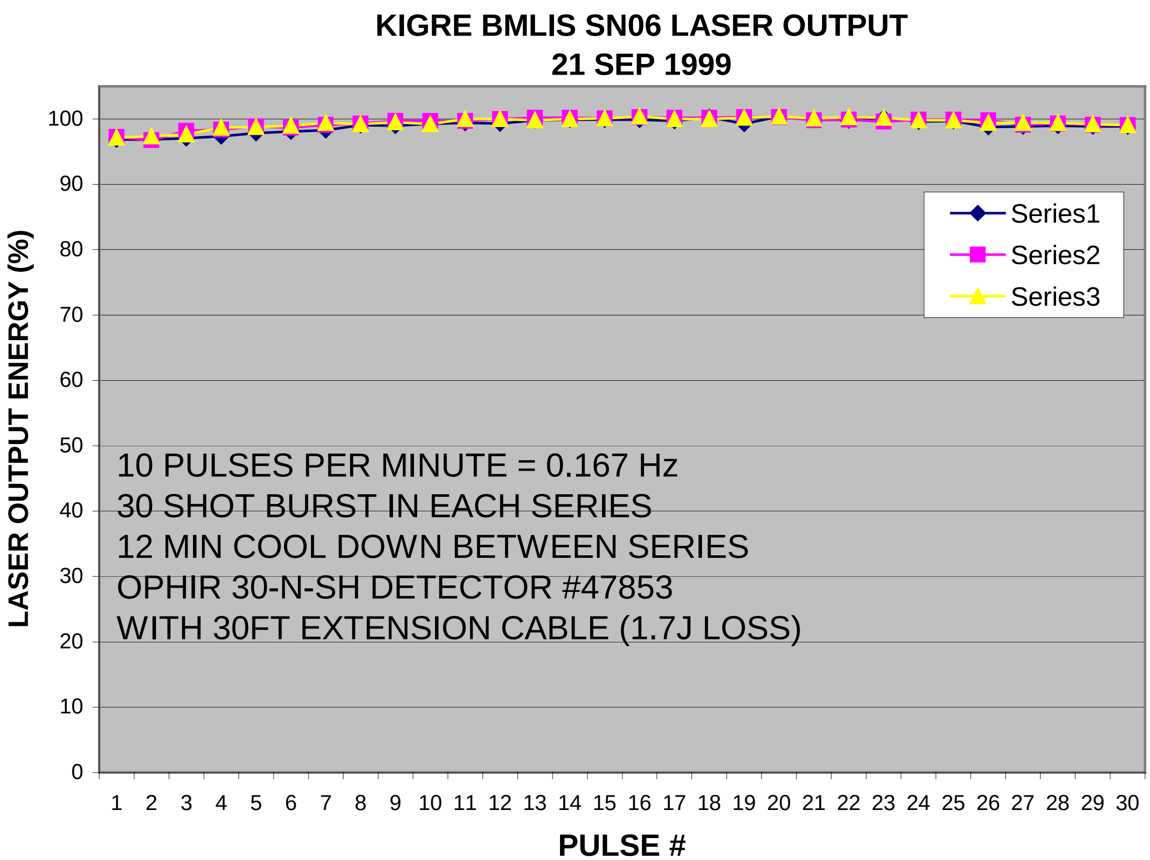


Figure 6

Power Supply

The power supply portion of the breech-mounted laser uses Kigre's advanced square pulsed technology and takes up a relatively small amount of space. For example, Kigre has successfully integrated the Laser Pulse Generator (LPG) with the Army Research Laboratory's experimental M198 howitzer Power Supply Distribution Unit (PSDU) using only the existing PSDU enclosure. The low average power of the pulsed breech-mounted laser system uses very little energy and does not require special voltage or current handling capabilities. The new NLOS-C System Demonstrator LPG is being designed to satisfy NLOS-C reduced weight, packaging, shock & vibration, E3 and EMP, Environment, and NUC/INR requirements.

Conclusions

Kigre's Breech Mounted Laser Ignition Systems have demonstrated that reliable direct propellant ignition is achievable. The potential for increased safety, reduced logistical burden, and improved environmental benefits can now be realized. Existing programs that can take advantage of a breech mounted laser ignition include the US Army's FCS NLOS-C Self-Propelled Howitzer (SPH), M109A6 Paladin SPH, the 9000 pound M777 Light Weight 155mm towed howitzer, and the M198 155mm towed howitzer.

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[iv] *Breech Mounted Laser Igniter for the 155mm Cannon*, S.J. Hamlin, JANNAF Interagency Propulsion Committee Workshop, 21 October 1996.
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[x] *SBIR Phase III Research*, ARDEC Contract #DAAE30-98-R-0521, US Army TACOM-ARDEC, Picatinny Arsenal, NJ 07806-5000

Principal Author's Biography

Christopher R. Hardy received a BS Electrical Engineering from the University of South Carolina Honors College in 1987. Mr. Hardy joined Kigre, Inc. in 1988 and has held the title of Chief Engineer and Laser Components Production Manager since 1999. Mr. Hardy has worked on a wide variety of electrical and electro-optical IRD&E efforts and has been a Project Engineer and Principal Investigator on various Government research and development programs.