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Laser Ordnance Ignition Capability at KSC

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Abstract

A laser ordnance demonstration system has been developed at the Kennedy Space Center (KSC) within the Launch Equipment Test Facility (LETF) to perform testing and evaluation of ground support equipment (GSE) and other items featuring laser-actuated initiators and other secondary ordnance for future vehicle programs. Its current form enables verification of firing dual redundant laser-actuated initiators by measuring their output pressure pulses, providing adjustable and measurable timing delays, and incorporating system checkout capability without requiring ordnance. The system comprises an electronics rack with required fiber-optic and other cabling to a secured test area within the LETF, where the initiators can be safely fired using appropriate test bombs, safety equipment, and instrumentation. It is designed to be easily merged with the LETF instrumentation and infrastructure normally used for testing and certification of GSE systems and articles. This capability enables the LETF, a unique facility extensively used in supporting Space Shuttle as well as other programs such as X-33, to evaluate the potential advantages of using laser ordnance technology for safety, cost savings, and increased reliability towards streamlining future processing and launch operations. Configuration design, as well as data and results from demonstration test firings of initiators, is presented in this paper.

Introduction

Ordnance ignition methods for aerospace GSE and flight hardware have always presented formidable tasks to operation personnel during storage, preinstallation testing, handling, installation, and verification to ensure safety as well as reliability of these critical elements. For the Space Shuttle program, the NASA Standard Initiator (NSI) was developed to mitigate some of these concerns experienced in previous NASA programs.

Laser-initiated ordnance technology represents potential advantages for launch site ground operations. It provides a possible increase in safety by eliminating the modes of inadvertent ignition and a potential decrease in processing time. Laser-initiated systems will eliminate constraints resulting from power-down times, radio frequency silence periods, potential static discharges, lightning protection, and humidity controls that must be imposed for safe ordnance operation on an electrically initiated system.

The effort described herein aims to provide an initial capability to perform testing with laser-initiated ordnance technology at the KSC. It is primarily to increase expertise within the KSC and contractor design organizations and help establish capability and expertise to test and evaluate future laser and fiber-optic control/instrumentation systems and components for in-house as well as external customers and organizations. This effort has led to the development of a laser ordnance demonstration system, or test bed, within the LETF at KSC.

Additionally, existing Space Shuttle requirements call for some ordnance devices to be tested from a lot at launch sites to verify the lot condition, as currently done by United Space Alliance (USA) Pyro group, per specification number 08080 Manned Spacecraft Criteria & Standards, P-2 Pyrotechnic Devices - Preflight Verification Tests at Launch Site. This may be also be required by other future launch systems that may use laser ordnance technology. The results of this effort may support such requirements.
Description of LETF

The LETF, where the laser ordnance test bed is based, is used primarily for testing GSE and GSE-to-flight interfaces for the Shuttle program at KSC. Recently, it has been used to support numerous other programs, such as the X-33 in testing of umbilicals and carrier plates and providing a refurbished and checked-out bridgewire-based hydrogen burn-off pyro system. It is used to qualify Shuttle equipment for launch pad operations as well as to support special engineering tests during GSE development. It has mechanical, pneumatic, and electrical shop support and instrumentation, safety, and quality infrastructure to provide flexible, impromptu GSE testing for varying needs. The LETF consist of several shop areas, a main instrumentation control room, and a launch-pad-oriented test yard with safe separation from personnel areas, power and instrumentation cabling, and corresponding distribution patch panels. These support various configurations for testing. In addition, the LETF works with various other instrumentation and metrology laboratories at KSC as required to support tests. It offers the experience and equipment infrastructure of testing and certifying for operational use of Shuttle GSE, as well as adaptable support capabilities for current and future vehicle development programs.

Design Rationale for Test Bed

Figure 1 shows a block diagram of the laser ordnance ignition test bed. In the typical testing configuration, one laser would operate one initiator with another laser/initiator pair in parallel for redundancy, replicating the actuation performed by typical electrical initiation systems in current GSE designs. The test bed enables testing up to two separate laser firing units firing simultaneously in parallel as described.

The ordnance of interest for this effort is the laser-initiated equivalent to the NSI for simplification of the instrumentation required for test firing. Thus, this will require the standard test for NSI, including the standard 10cc test bomb and two pressure transducers to record redundantly the pressure pulse from the initiator firing.

The laser firing units are situated in the LETF pumphouse, which is located toward the middle of the test yard, because the length of the fiber-optic harness ordered is 100 feet. This constraint is because the laser diodes are not powerful enough to reliably fire the laser initiators from the LETF control room, which is 350 feet away. Thus, a rack with the laser firing units and the other electronics was located in the pumphouse, an air-conditioned area suitable for electronic equipment.

The testing on the laser initiation systems within this test bed facility will focus on parameters such as firing delays and skew between "simultaneous" firings, repetitiveness of firings, fiber-optic connection constraints and effectiveness of check-out methods (built-in or otherwise), and overall installation and operation of the test bed facility. Any degradation of the lasers and harnesses with usage and time will also be observed.

System firing delays typical of current Space Shuttle electrical bridge-wire systems are in the millisecond range and skew times required between A and B redundant systems may be as low as 0.1 millisecond. Using this as a guide, the test bed design includes the capability to vary skew timing not only to compensate for fixed offsets in the system but to introduce controlled skew for engineering test purposes. This has been done in the past for Shuttle hold-down post testing.
Description of Test Bed

The test bed's current form enables verification of firing dual redundant laser-actuated initiators by measuring their output pressure pulses generated within the test bombs, providing adjustable and measurable timing delays, and incorporating system checkout capability without requiring ordnance. It is designed to be easily merged with the LETF instrumentation and infrastructure normally used for testing and certification of GSE systems and articles. The transducer amplifier and laser pulse detector outputs, as well as other signals, can be routed to a control room rack via the appropriate LETF instrumentation patch panels from the pumphouse rack or the test area.

The basic function of the test bed is for two lasers (A and B) to redundantly fire pulses through their respective fiber-optic harnesses to each ignite an initiator installed in a containment test bomb within a hardened safety container. The pressure pulses from each initiator are then measured by redundant transducer pairs (1A/2A and 1B/2B), and the output of their respective amplifiers is captured on the digital storage oscilloscope. The A/B delay and skew adjustment circuit is existing test equipment that has been used in previous testing at the LETF to enable adjustment of the timing for the commands to GSE pyro systems. This unit provides the required signals, reduces the amount of electronics nonrecurring engineering design for the project, and helps maintain similar configuration as used in previous GSE pyro system testing. The arm and fire commands and other associated signals are interfaced to the laser firing units through appropriate controlling equipment, depending on the type of laser system being used.

The heart of the measurement is the oscilloscope traces showing all four pressure transducer signals relative to each other with respect to the triggering fire command, which also triggers the oscilloscope. It is a fast, 4-channel digitizing oscilloscope with a GPIB port, for possible future interfacing to a data acquisition system, and an on-board 3.5-inch floppy disk drive for storing the data for portability.

Temporary test equipment is used to verify the status of the test bed and measure its operating parameters. It is disconnected before ordnance firings. A KSC-built 2-channel laser pulse detector is used to display the pulse shapes on the scope while a commercial off-the-shelf laser energy meter is used to measure single pulse energies. In addition, a fiber-optic loss test kit is used to determine if the fiber attenuation is changing over time and number of firings. The source and the meter combination are NIST traceable and read out directly in dB and dBm. A fiber-optic microscope is used for inspection of fiber-optic connector ends.

Two laser technologies are being tested for comparison, each offering its pros and cons. A diode laser system was used to obtain the data presented here, and a rod laser system will be studied pending final installation and testing. Diode laser systems typically offer a smaller size, better control of pulse timing and thus pulse energy, and lower input power requirements, but also tended to be relatively limited in power (although this is rapidly changing) and to one device per laser. Rod laser systems have typically higher power outputs and are capable of activating numerous devices simultaneously from the same laser. Yet, rods typically have the drawbacks of larger packaging, high-voltage requirements, along with more controlling electronics. Both laser systems acquired operate in the near-IR region: the diode laser system emits 920-nanometer wavelength, and the rod laser emits in 1064 nanometers (Nd:YAG). The diode laser system uses 100-micrometer core fiber optic, whereas the rod system requires 200 micrometers. The larger core size for the rod system is due to the larger power attained.

Other desired future additions shown include a data acquisition and storage system included for future plans to automate data gathering, envisioned as a personal computer running LabView software, and an
optical time domain reflectometer (OTDR) to implement a Built-In Test (BIT) capability for the rod laser system, enabling verification of optical path continuity to the initiator device prior to firing.

Laser initiators for each laser system type were acquired that mechanically fit the NSI test bomb and produce pressure output meeting the NSI performance requirement. The all-fire level for the diode system initiators is estimated to be 1.58 millijoule and that of the rod system approximately 23 millijoule. The diode laser initiators also included a spectrally selective filter to enable system self-testing.

Demonstrating the BIT capability for each system was one of the objectives of the effort, enabling verification of system readiness just prior to ordnance firing. To this end, the diode laser system acquired contained a BIT test feature using a safe, below no-fire energy test laser to illuminate a spectrally selective filter built into the initiator through the fiber-optic cable. The reflection for the test laser wavelength is then used by the system to measure and report a good optical path from the laser through to the initiator. Yet, the optical filter passes the firing laser wavelength into the explosive grain as required for ignition. In the case of the rod laser system, it has provisions for directly installing an OTDR externally for similar verification.

The test bombs used are as specified for NSI testing in SKB26100066, Design and Performance Specification for NSI-1. They have an internal volume of 10cc and were fabricated per drawing SEB26100021.

Data From Device Testing

A typical laser pulse detector trace is shown in figure 2 for both lasers configured to fire simultaneously out of the laser diode system. The plot shows the voltage output signals for each laser detector channel as a function of time, with time zero corresponding to the triggering edge of the fire command from the A/B delay and skew control.

Although both pulses appear of similar magnitude, the detector gain for channel A has been adjusted to increase its output to be comparable to channel B. In fact, laser channel A has an energy of about 0.5 millijoule, whereas channel B is about 1.5 millijoule. The average energy values for these pulses were determined from multiple laser firings using the laser energy meter in separate measurements.

Worth noting in figure 2 is that the observed pulse shapes are close to square, and their width and delay timing are very synchronized, the widths being consistently 9.2 milliseconds and the delays from the trigger edge being between 0.7 and 0.8 millisecond with near 0 skew between laser pulse edges for this time resolution.

Figure 3 shows a combination of data from two separate device firings compared to similar manufacturer data. The outputs of the transducer amplifiers are shown with time during an initiator firing. Two sets of transducer curves are shown, each from a separate firing for comparison (first firing and second firing). Also shown is a smoother curve from a comparable measurement by the manufacturer.

The delay in the pressure pulse rising edge for the manufacturer data is observed to be under 1.5 milliseconds, whereas that of the KSC test bed generated data is approximately 5.9 milliseconds. This increased delay for the test bed generated data is thought to be due to the degraded energy level of the diode laser (approximately 1.5 millijoules) relative to the all-fire level of the device (estimated 1.58 millijoules). It is presumed it takes longer for the thermal process of grain ignition to occur at the lower energy level. Arguably, it still meets the required output performance for the NSI specifications: peak
pressure of 650± 125 psig peak in a 10cc closed volume and 525 psig within 10 milliseconds or less; the vertical scale of the graph is 100 psig per volt. The system has since been returned to the manufacturer for refurbishment.

Several possibilities are being evaluated regarding the differences in curve shapes, specifically the more rapid pressure decay for the KSC data. One possibility is dynamic leakage in KSC test bomb, although this is thought highly unlikely since (1) test bombs were checked for static pressure up to 1,000 psig and proved leaktight, (2) all pressure transducer torquing and installation instructions were properly performed, and (3) no blow-by gas indications were observed around the o-ring sealing the test bomb cap and body or any of the parts. Another possibility being considered is whether weakened laser energy may also affect this rapid tailoff; since presumably considerably higher laser energy beyond the all-fire level was used in the manufacturer measurement. The manufacturer discounts this since the typical effect observed from reduced laser energy is only prolonged response time. It must also be noted that the transducers amplifier outputs had different cutoff frequencies, the manufacturer's curve having 10-kilohertz filter, whereas the KSC equipment was set from the factory to 180 kilohertz. This filtering may explain the elimination of the higher frequency oscillations from the manufacturer's data, so evident in the KSC-generated curves, generally understood to be due to superposition and cancellation of pressure waves inside the test bomb volume during ignition. On further discussion with the manufacturer, it was also learned the manufacturer's test bomb has a different configuration, with depth-to-width ratio close to 1:1, than the KSC's test bombs, which have a depth-to-width ratio closer to 1.68:1. This can affect not only the pressure wave interference pattern in the test bomb volume but also the gas thermal process affecting the tailoff in pressure decay. All of these possibilities are being examined and discussions with the manufacturer are continuing.

Conclusions/Summary

The LETF at KSC offers a facility to check out GSE or other similar items to developers of aerospace vehicles. The laser ordnance ignition test bed being developed enhances this capability by providing the ability to test GSE incorporating laser ordnance technology with instrumentation and experience used in previous launch systems. The LETF can be used to help facilitate design and development efforts for future GSE, as well as to support testing and certification. Work is continuing to complete the laser ordnance test bed testing and to publish a final report.

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Figure 1. Conceptual Laser Ordnance Testbed Configuration (Typical)
Figure 2. Typical Laser Pulse Detector
Figure 3. Pressure Pulse Data - KSC and Manufacturer