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DEVELOPMENT AND PRODUCTION OF TWO
EXPLOSIVE COMPONENTS USING SCB TECHNOLOGY

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ABSTRACT

For many years, explosive components have used hotwires to convert an electrical stimulus into the thermal energy required to initiate the device. A Semi-Conductor Bridge (SCB) performs the same function, but with the advantage of requiring approximately 1/10 the input energy of a comparable hotwire, while retaining excellent no-fire characteristics. The SCB also demonstrates faster function times due to its inherently-lower thermal mass. This paper discusses the development and production of two SCB-based devices, the MC4491 Initiator and the MC4492 Actuator. The initiator is designed to shock initiate a linear shaped charge by accelerating a thin metal plate across a small gap. The actuator functions several different components, serving as either an actuator by producing a rapidly expanding gas to activate piston mechanisms or as an ignitor by providing hot particles for initiating pyrotechnic mixtures. Details are provided on the construction of both devices, methods of assembly, and performance characteristics (function time, flyer velocity, pressure in a closed bomb, heat content, and no-fire and all-fire levels).

Introduction

The MC4491 Initiator and MC4492 Actuator represent the first production of SCB-based explosive components for the Department of Energy. Both devices are being designed for use in the SafeGuards Transporter (SGT) to function a number of mechanical or explosive subsystems. The initiator is designed to produce a high-velocity metal plate to cause functioning of a linear shape-charge element.

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The dual role of the actuator is to generate high pressure gas to actuate mechanical pistons and hot debris to ignite pyrotechnic compositions.

One of the objectives during the development was to share commonality of many features between the two devices. Except for the mating threadform with the next assembly, the two devices outwardly appear nearly identical. By using different thread sizes, interchange of the devices is avoided during SGT buildup.

The semiconductor bridge (SCB) was selected for this application primarily because of its lower energy requirement¹.

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The semiconductor bridge (SCB) was selected for this application primarily because of its lower energy requirement¹, approximately one-tenth the 30 mJ normally needed by a 1 ohm hot-wire device. The SGT has a number of these explosive devices which are designed to operate independent of outside power sources. By reducing the overall firing set power levels, the on-board systems can be downsized accordingly.

To-date, two development lots of these units have been completed with a third expected to be finished by the end of this year. This last lot of over 500 units will use production tooling and established processes. The first production lot is expected to be scheduled for 1997.

Description of Explosive Components

The MC4491 Initiator and MC4492 Actuator were developed concurrently following the establishment of the SGT system requirements. Although the two devices share many features, numerous aspects are distinctly different to perform the desired function. The components are described separately in the paragraphs below. Of the three versions, only the latest is discussed unless details of the earlier models are needed to clarify the discussion.

MC4491 Initiator

The performance goal for the initiator is to reliably produce a high-velocity flying metal plate, when initiated by a low-voltage capacitor discharge firing pulse. It uses the deflagration-to-detonation transition (DDT) of the explosive CP {2-[5-Cyanotetrazolato] pentaamminecobalt (III) Perchlorate}². The ignition increment consists of a medium-density pressing (25 ksi) of the powder against the dual SCB elements, followed by the low-density (pressed at 10 ksi) DDT column and HMX (cyclotetramethylene tetranitramine) output increments (Figure 1). The unit is assembled in two sections, the header with the ignition powder and the barrel with the remaining explosive. After powder loading, the two sections are joined by laser welding the mating girth seam.

Figure 1. Schematic of MC4491 Initiator

The header and connector shell are made from Type 304L stainless steel bar stock machined to final dimension. The mating connector is an MS3116-8-45 using bayonet style locking tabs. The four 0.040" diameter pins are an iron-nickel alloy allowing good adhesion to the Corning No. 9013 seal glass. The close proximity of the metal surrounding each pin provides a high-voltage breakdown for electrical transients such as static discharge.

Conventional bridgewire designs typically bond the wire element to the exposed ends of the electrical feedthrough pins. The SCB, however, must use small diameter wires to connect from the lands on the die to the pins. The SCB selected for this application is a Type 3-2, as shown in Figure 2.³ Nominal overall dimensions for a single die are 45 x 50 mil by 20-mil thick. For a dual unit as used here the 45 mil dimension increases to 90 mil with the remaining side and thickness staying constant

Figure 2. SCB Description and Installation

The sealing glass also forms the surface for mounting the SCB assembly. After the glass sealing process, the charge cavity is formed by machining to the final dimension. The size of the SCB element, relative to the pin spacing, causes the edge of the pin to be close to the boundary of the die. To avoid placing the interconnecting wires over the sharp edge of the die, a 160-mil diameter by 20 mil deep counterbore is machined into the surface of the glass, centered between the pins. The SCB element is then epoxy-bonded into the cavity so that the pin and SCB surfaces are level. The interconnect wires are 5-mil diameter gold and are attached to both surfaces using ultrasonic welding.

The ignition pressing is contained within a polyetheretherketone (PEEK)⁴ charge holder that is surrounded by a steel ring to support the powder during pressing. The PEEK also provides electrical isolation between the pin surfaces and surrounding metal parts. Earlier versions did not use the metal outer ring and the limited tensile strength of the PEEK prevented using high pressure levels. The powder is loaded in a single increment at 25 ksi so that the powder is flush or slightly above the mating metal surface. Early designs used two increments for the ignition charge, but some damage was caused to the SCB by the apparent insufficient thickness of powder. The small metal shoulder of the header locates the charge holder and prevents beam penetration to the powder during the girth welding operation.

The barrel section is fabricated from SS304L bar stock and machined to final dimension. Its relatively large diameter (7/16-20 UNF thread) is designed to provide good confinement to the DDT column. Experience has shown that for a 0.080" diameter explosive column, the transition process and the flyer velocity are optimized when the barrel wall thickness is at least 0.15".⁵ The threads allow the device to be mated to the next assembly. The barrel is loaded in reverse order to allow the HMX powder to be pressed to 40 ksi, optimizing the output impetus supplied to the closure disk. The 0.005" thick seal disk is first laser-welded to the machined barrel. The HMX is then pressed against the seal disk in two separate

increments. This approach provides intimate contact between the explosive and the seal disk, ensuring that the disk forms an intact flying plate. The DDT column is loaded in three separate increments, the first two pressed at 9 ksi and the last at the same pressure but "dead-stopped" at flush with the mating metal surface.

Mating of the assembled header and barrel causes the two explosive interfaces to come into intimate contact. The laser girth weld has a typical penetration of 0.020 to 0.025" ensuring good mechanical strength.

The MC4492 Actuator

The MC4492 Actuator is shown in Figure 3. The header design is very similar to the MC4491 and will not be discussed in depth. For the actuator the barrel is welded to the header first, before loading the powder. Unlike the initiator, the thread form on the actuator is 3/8-24 UNF, preventing using the wrong unit during SGT assembly. A polycarbonate charge holder is epoxy-bonded inside the header to form the powder cavity. The ignition charge and gas generator is 50 mg of titanium subhydride-potassium perchlorate (THKP), pressed at 12 ksi. This is followed by 205 mg of the copper oxide/aluminum thermite, which uses an inter-metallic reaction to produce molten copper and aluminum oxide. The thermite powder is pressed at 12 ksi.

Figure 3. Schematic of MC4492 Actuator

In order to maintain the powder column in intimate contact with the SCB during all temperature extremes, it is necessary to

compensate for the relative difference between the explosive column and the surrounding metal parts. This is accomplished in the MC4492 by using a combination of elastic compression pad and a curved metal closure disk. The compression pad is made of 12-mil thick RTV rubber⁶. The seal disk is 5-mil thick SS304 formed with a centered spherical curvature of 0.5" radius. This is combined with a 22-27 mil raised lip to allow the disk to fit snugly into the bore of the barrel. The final assembly of the actuator consists of pushing on the seal disk to achieve 50% compression of the RTV pad, then laser welding around the periphery of the lip to closure interface. Constructing the seal disk in this manner allows slight positional changes relative to the bore to compensate for variation in the final powder column height.

For those applications where pressure sealing is required, the MC4492 Actuator is equipped with a ThredSeal® to provide an o-ring seal between the face of the unit and the next assembly.⁷ This method provides a pressure seal capable of withstanding static levels in excess of 10,000 psi, while the glass seal in the header is good to pressures above 17 ksi.

Performance Test Results

The MC4491 Initiator and MC4492 Actuator are designed to meet performance standards based on SGT system requirements. The safety-related specifications include: 1 amp/1 W No-fire level, immunity to electro-static discharge, isolation resistance from bridge to ground, and insensitivity to RF exposure. For reliability and performance the requirements specify: .999 reliability (at 50% confidence) All-fire threshold (within the allowable function time), minimum flyer velocity for the initiator, peak pressure and pulse duration and thermal output for the actuator.

Because of the limited quantity of units available from the first two development lots, only limited testing has been completed to date. Activities in FY95 with the third lot devices will concentrate on completing the safety, reliability, and performance efforts.

Based on a ten-unit Langlie⁸ test, the MC4491 Initiator demonstrated a 90% No-fire threshold of 1.1 amp for five minute exposure. In a similar manner, the MC4492 Actuator showed a threshold at 1.2 amp (for five minutes). Two models for electrostatic-discharge are available, the Sandia Standard Man⁹ that has been used for DOE weapons systems for many years, or the "Fisher Model"¹⁰ that has recently been developed and is gaining considerable acceptance. Although these devices have not been tested, similar components using both CP and THKP have been exposed to the Sandia Standard Man waveform.¹¹ The testing indicates that the resistance of the SCB increases slightly (<10%) with exposure to a single pulse, but is unaffected thereafter with subsequent pulses. In all cases the devices functioned as intended when supplied with the appropriate firing signal. More extensive testing will be performed on the third lot of initiators and actuators.

The SGT has not specified the RF threat environment to date, however, the MC4491 and MC4492 have been exposed by direct injection of the RF signal into the SCB through the electrical pins. Each device was exposed for five minutes at two different frequency ranges; first at 10 MHz and 1 W, then at 450 Mhz and 10 W. Following each exposure, the bridge resistance was checked and no significant change was noted for either component. Each of the devices were then function-tested and to determine if the exposure caused adverse effects. The results of these tests are discussed below. The second portion of the RF study was to increase the power applied to the unit until initiation occurred. The initiator fired at 6 and 15 W for the 10 and 450 MHz ranges, respectively. The actuator functioned at 15 W for the 10 MHz frequency. For 450 MHz, the unit failed to initiate before reaching the upper limit of the testing equipment (25 W).

Traditional hot-wire detonator designs relied on high density pressing onto the bridgewire to insure good heat transfer for ignition. At the start of this development, it was not clear that the SCB required the same approach, particularly considering that the firing set uses a capacitor discharge instead of constant

current. This, combined with charge holder cracking problems at high pressing pressure levels, prompted a study of the effect of powder density on all-fire voltage levels. The results are shown in Figure 4 as a plot of the mean all-fire threshold as a function of the pressing pressure. The trend in the data is the same characteristic behavior as a hot-wire device with the highest pressure (nee density) giving the lowest threshold voltage. Unlike a conventional device, however, the difference between the means at 40 ksi and 25 ksi is only 1.4 volts, or less than 12%. This suggests that the efficiency of the SCB is not as closely tied to the powder density.

It should be noted that the all-fire levels presented in Figure 4 are for devices connected to the firing set by means of a 35' long coaxial cable. This was done to simulate the worse-case situation in the SGT where several devices are located far away from the initiation source. The voltage was measured at the device using a differential probe to prevent common-mode voltage errors.

Performance testing of the initiator consists of measuring flyer velocity using VISAR (Velocity Interferometer System for Any Reflector)¹². A typical record is shown in Figure 5 as flyer velocity as a function of time, measured from the before motion begins until the flyer moves out of the focal range of the instrument. The second curve is the displacement of the disk as a function of time, obtained by numerical integration of the velocity data. Time is in μs (1×10^{-6} s), the velocity results are in units of $\text{mm}/\mu\text{s}$ (km/s), and the displacement is in mm. Because a

dual-leg VISAR was employed¹³, each result is actually two separate measurement of the same phenomena. This is more obvious in the displacement data at late time where the two results begin to differ. The close agreement of the two measurements indicates the data to be of high quality.

Figure 5. Velocity and Displacement as a Function of Time

The velocity data are typified by an initial sudden "jump" from rest to nearly $1.5 \text{ mm}/\mu\text{s}$. Because the VISAR measures the particle motion at the surface of interest, the oscillations in the leading edge of the record represent "reverberations" as the shock wave in the flyer reflects from one free surface to the other. The duration of each oscillation is equivalent to the compressed thickness of the flyer divided by the shock velocity in the material at the achieved pressure level. With each oscillation, the velocity of the flyer increases until the entire thickness is at the equilibrated stress state (approximately five oscillations required). The peak velocity is on the order of $2.8 \text{ mm}/\mu\text{s}$ and is attained at a propagation distance of about 1.5 mm.

The nearly-linear behavior of the displacement data reflects the velocity profile in that most of the acceleration occurs over a very short time span at the start of motion. Likewise, the favorable signal-to-noise level in the records, even at distances well beyond any practical application, indicates that the flyer reflectivity is unchanging. This in turn suggests that the flyer plate is intact and not breaking up into fragments. The slight divergence in the two records at later times is caused by the slight increase in the noise as the flyer moves away from the focal point of

the system. A more useful representation of the data is given in Figure 6, in the form of velocity as a function of displacement. This allows quick assessment of the velocity at any distance of interest, such as the location of the next assembly. For the SGT system, the standoff distance is specified at 2.0 mm (0.080"). This placement is optimum because the velocity is at a maximum and the it assures that breakup of the flyer is minimized.

Figure 6. Velocity as a Function of Displacement

The performance test apparatus for the MC4492 Actuator is the bomb calorimeter, as shown in Figure 7. The design has a volume of approximately 10 cc and it intended to minimize the mass of the apparatus to promote a large temperature change from the products of the actuator. Each calorimeter is instrumented with two thermocouples to measure the temperature rise and a single transducer to monitor the pressure change. The unit under test is installed in the calorimeter and the entire assemble placed in a large block of insulation to minimize external heat transfer. High-speed digitizers are used to record the output from the detectors.

Figure 8 is a representative plot of the pressure developed in the bomb calorimeter as a result of an actuator test. As expected, the pressure increases quickly as a result of the gas generation and heating of the internal volume. The gradual decay represents the cooling of the generated gas and debris. The equilibrium temperature attained was on the order of 200 °C, occurring approximately 60 s after the functioning of the device. It is estimated that the THKP will produce relatively little permanent gas, on the order of

10 psig.¹⁴ The pressure curve returns to a level corresponding to the final temperature of the gas volume.

Figure 7. Schematic of Bomb Calorimeter

Figure 8. Pressure In Bomb Calorimeter

Lessons Learned

The two development versions of each device have provided valuable lessons on the construction of SCB-based components. The main consideration with any interface to the SCB is to ensure that the powder remains in close proximity to the die under all environmental conditions. Compression pads may be needed if differential thermal expansion of the materials can cause the powder column to change size relative to the housing. This is not a problem with the CP powder but it must definitely be accounted for with the THKP used in the actuator. In a similar manner, the threaded barrel must be robust enough so that the tightening torque does not allow the deformation of the body. If a normal thread relief is employed with the actuator, the body has insufficient strength to resist stretching of the housing during normal tightening of the unit into the next assembly.

Two types of failures were prevalent with the SCB installations. The most common was related to the small diameter aluminum or gold wires used to connect the die to the exposed pins. Typically, the condition of the wire material was very soft to promote easy bonding and manipulation. If any portion of the wire was unsupported, the pressing of the powder would often cause stretching and failure. To avoid this, it was necessary to support the wires with epoxy after installation.

The second problem involves the placement of the die on the glass substrate. If the SCB did not lie on a flat surface, it typically would crack during the pressing operation. This was eliminated during development by ensuring that the counterbore cavity was sufficiently large to place the corner radius outside the perimeter of the die. It was also necessary to clean the cavity prior to die installation to remove foreign material that could be trapped under the chip.

Conclusions

The MC4491 Initiator and MC4492 Actuator have undergone a rapid development and are nearly ready for production. The third and final version is presently under construction and should be tested and delivered before the end of CY95. The use of an SCB for the initiation element allows the devices to be used in applications where the firing energy is limited. The SCB shows promise for improved safety and performance capabilities.

The MC4491 Initiator has demonstrated the capability to accelerate a 5-mil steel disk to velocities in excess of 2.8 mm/ μ s, in a distance on the order of 1.5 mm. Additionally, the flying disk appears to remain intact for distances well beyond that required for the required application. The MC4492 Actuator produces both gas pressure and hot debris for its dual role as an actuator and an ignitor. Peak pressure in excess of 300 psi has been measured in a 10-cc bomb, while the thermal output is greater than 1000 cal/g. The heated debris includes molten copper and aluminum oxide droplets.

The first production lot for both components is scheduled for CY97. Prior to starting, all procedures, tooling, and acceptance test equipment will be qualified by Sandia National Laboratories.

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