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ADVANCED CARTRIDGE DESIGN FOR THE TERM-KE ROUND

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Development of conventional solid propellant gun charge solutions for high performance ammunition has become increasingly difficult. Limits on system parameters such as loading density, barrel erosion, and propellant energy have made progress slow. Over the past several years a team lead by the US Army ARDEC, Alliant Techsystems, and Veritay Technology have been working to create a high performance propulsion system for an advanced 120 mm tank round. The resulting technological solution has wide application in other high performance systems. One key to achieving increased performance, without incorporating extremely high temperature, erosive propellants, is to obtain a high loading density using propellant consolidation. The program team developed a thermal consolidation technique achieving propellant loading densities of up to 1.45 g/cc. This paper will address the development of the consolidated charge and a unique pulsed ignition system that results in consistent muzzle velocity independent of temperature.

INTRODUCTION

The Tank Extended Range Munition – Kinetic Energy (TERM-KE) program has been, for the past 5 years, developing a cartridge configuration which would meet the unique requirements of this system.

The challenges in successfully gun launching the TERM-KE projectile are numerous. For a 120 mm bullet, the XM1007 is very large, weighing around twice that of a conventional 120 mm projectile. The projectile is 970 mm (38.2 in) long before launch. Since the 120 mm interface requires a maximum cartridge length of 984 mm (38.7 in), very little room is left for cartridge components such as the case base and primer, this is illustrated in Figure 1. Unlike other 120 mm projectiles, which taper at the aft end, the TERM-KE projectile maintains its maximum diameter for most of the length of the cartridge. This results in less than one-half the available chamber volume as conventional 120 mm kinetic energy ammunition, for a propelling charge.

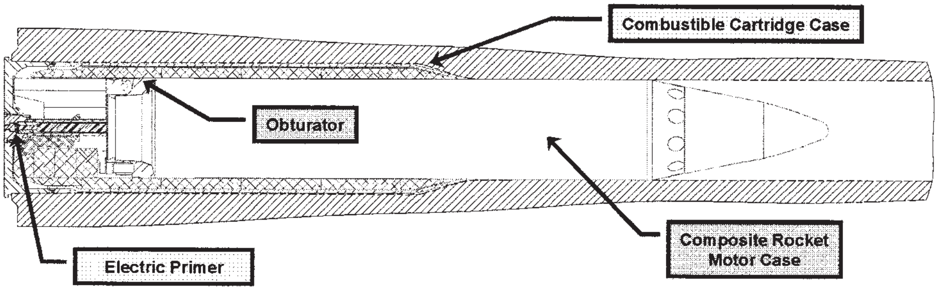

Figure 1. The TERM-KE projectile rests against the cartridge case base.

The inability of the rocket motor case to structurally withstand the full ballistic cycle pressure requires that the obturator be located at the aft end of the rocket motor case. As a result, the projectile must travel over 400 mm (16 in) before the obturator seats in the barrel. Since the rocket case is protected by the rear obturator, its design is optimized for the acceleration loads and rocket motor operation. This limits its ability to carry an external pressure load to around 70 MPa (10,000 psi). This combination leads to the requirement that the projectile must move at least 400 mm (16 in) before the gun pressure reaches 70 MPa (10,000 psi). The guidance electronics and structural design limits the maximum acceleration which can be imparted on the round to 20,000 g's. This means the cartridge must operate at substantially less than the design operating pressure of the 120 mm cannon.

To meet these requirements a unique ignition system has been developed: the Smart Cartridge System. This system involves an electronically controlled ignition system which allows the projectile to clear the chamber before the main charge is ignited. Testing in February of 1999 demonstrated that the XM1007 Smart Cartridge System not only exceeded velocity requirements, but also provided a flat muzzle velocity performance over the temperature range: muzzle velocity at cold = muzzle velocity at ambient = muzzle velocity at hot.

RESULTS AND DISCUSSION

Over the development life of the program, four propulsion concepts have been explored to meet the TERM-KE requirements. The first concept used a black powder/CBI booster charge and inhibited JA2 sheet and disk propellant. The booster charge was used to translate the projectile while the inhibitor delayed ignition of the JA2 until the obturator traveled into the barrel. While this concept showed some early promise, it was discovered that a large amount of inhibitor was required to achieve the appropriate ignition delay and that uniform application of inhibitor to the large number of sheets and disks in the charge was difficult.

The next two concepts used an ignitor tube to translate the projectile. The ignitor tube was a solid walled tube which was assembled into a matching fin support tube attached to the projectile. The tubes were locked together with a nylon shear ring. A small charge was ignited inside the tube by the electric primer. The ignitor tube reached a pressure of around 140 MPa (20,000 psi) and translated the projectile forward 100 mm (4 in) before venting. Upon venting, an ignitor charge consisting of black powder bags ignited, starting the ignition of the main propelling charge. This process is illustrated in Figure 2.

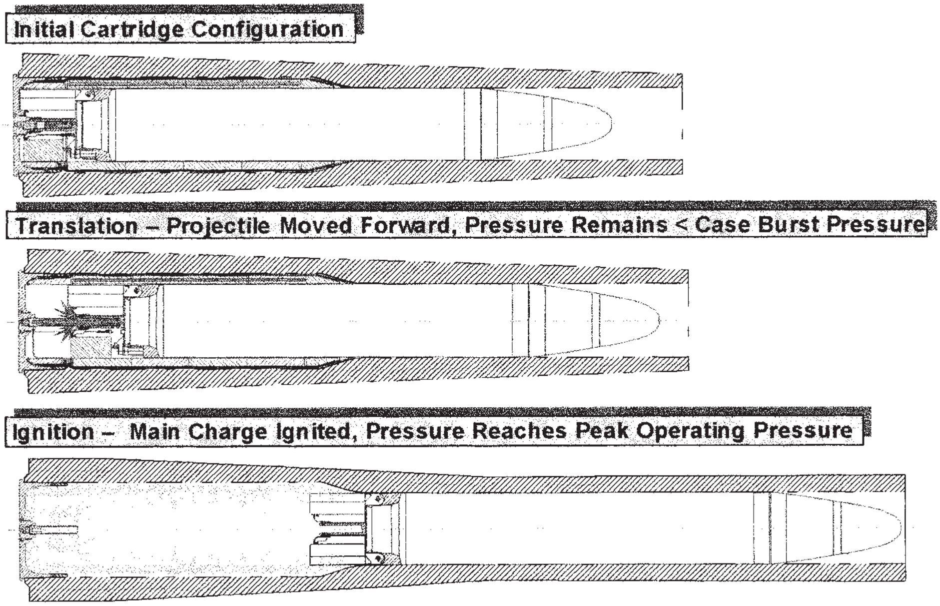

Figure 2. Early operation stages of the TERM-KE cartridge.

The main propelling charge used concentric wrap sheet JA2 propellant. Although this concept required less propellant inhibitor than the earlier concept, uniform and repeatable application of this inhibitor was still problematic.

The second, and most successful concept, used a consolidated, single perforation JA2 propellant. The JA2 base grain was manufactured at the Alliant Ammunition and Powder Company, Radford Army Ammunition Plant. These grains were then coated with an inhibitor, known by the trade name of Vinsol. This Vinsol coating not only inhibits the ignition of each grain, it also adds structural strength to the consolidated charges. The propellant was then processed, under heat and pressure, into consolidated charges by Veritay Technology Inc. This process is shown in Figure 3. Once the consolidated charges were completed, the assembly of the cartridge was very simple, taking less than 3 minutes to complete (Shown in Figure 4.)

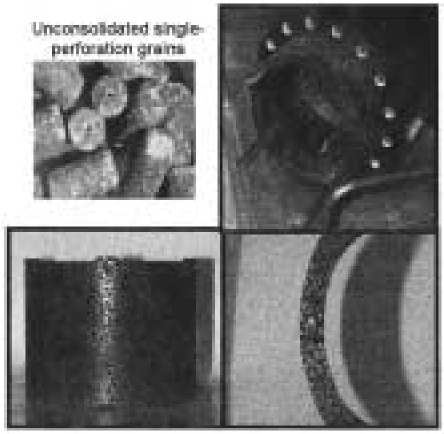

Figure 3. TERM-KE consolidated JA2 propelling charge manufacturing.

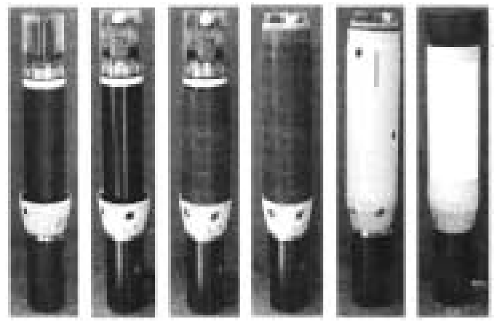

Figure 4. Assembly steps of a consolidated charge TERM-KE cartridge.

The consolidated charges were manufactured at densities up to 1.45 g/cc (0.052 lb/in^3). This density, and the fact that the consolidated charges can be made to follow the contours of the case and projectile, allowed for very efficient packing and the maximum propellant load. The fact that each propellant grain was inhibited ensured that the ignition is delayed, even if the charges broke up from rough handling or ignition. However, as was discovered during testing, this consolidation process also made the charges difficult to ignite consistently, especially over the temperature range.

Figure 5 illustrates the two most common ignition configurations for the consolidated charge testing. Most early testing was conducted with round bags, as shown on the left, loaded with black powder. These bags, as well as the surrounding consolidated fin charges, were attached to the projectile fins so that they translated with the projectile and were lined up with the ignitor tube when it vented. A second configuration, consisting of finger bags shown on the right, was also tested. Both configurations, when combined with optimization of propellant granulation and inhibitor level, were able to deliver the required performance at ambient temperature levels. It was discovered that by varying the amount of propellant contained in the ignitor bags and the number of ignitor bags in the round, the ballistic performance could be greatly effected.

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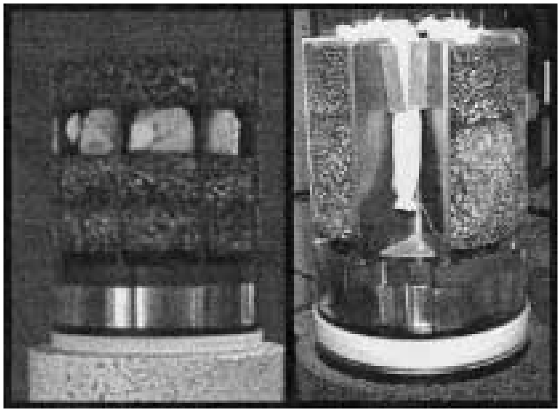

Figure 5. Two different ignitor bag configuration tested with consolidated charges.

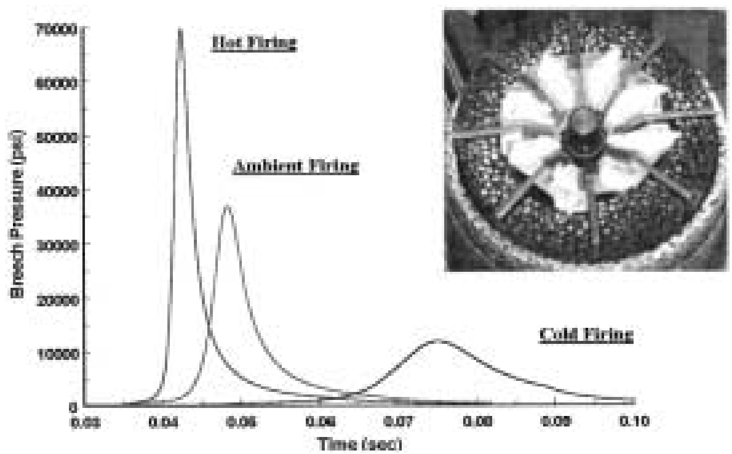

Figure 6. Results of test firing over temperature for conventionally ignited TERM-KE cartridges.

Once testing over the operating temperature range was begun, the sensitivity to the ignition impetus became an extreme liability for this configuration. Figure 6 shows the results of a group of test firings over the operating temperature range. The velocity and pressure spread from hot to cold was very high. With the translating projectile, all of the temperature effects are magnified:

Hot:

- Ignitor bags light easier, burn quicker
- Inhibitor less effective, propellant ignites quicker, burns faster
- Moving projectile, less time provides less free volume

Result: High Pressure (200% of Ambient)

Cold:

- Ignitor bags harder to light, burn slower
- Inhibitor more effective, propellant ignites slower, burns slower
- Moving projectile, more time provides more free volume

Result: Low Pressure (25% of Ambient)

These same results were repeatedly encountered when cartridge modifications were made such as ignitor bag changes, live/inert cartridge case, and changing the translation velocity. In late 1998 the TERM-KE team determined that an entirely different approach was required to solve this problem.

It was apparent after evaluating the test results, that the ignition of the main propelling charge was the critical parameter in controlling this system. A design effort was begun to develop a new ignition system, which would be independent from the ignitor tube. Previous testing had been conducted with a charge of Benite sticks in the ignitor tube. This provided a strong ignition impetus when the tubes separated, and was capable of lighting the JA2 charges, even without the Black Powder ignitor bags. To uncouple this event, the Benite was replaced with Green Dot smokeless shotgun powder. This charge provided a similar translation velocity, but did not light the JA2 upon the venting of the tubes.

With the ignition event now uncoupled from the ignitor tube, a secondary ignition system needed to be developed. Experience has shown that the consolidated charges need a strong uniform ignition system to provide optimal performance. To achieve this, a candelabra ignitor was developed. To provide a uniform ignition of the charge, 4 candelabra arms were fed down molded holes in the main consolidated charges (Figure 7). This provided an ignition length of 400 mm (16 in) along the charges. To provide a quick ignition along this length, the candelabra utilized of Rapid Deflagration Cord (RDC). RDC is a sheathed cord which burns at a rate from 125 to 200 m/s (5000 to 8000 in/sec). This produces a near simultaneous ignition of the bulk of the main propelling charge. The RDC was ignited with a semi-conducting bridge squib.

The combination of the ignitor tube and the candelabra ignitor provided the TERM-KE cartridge with a two-pulse ignition system, with each pulse controlled individually. This allowed for the ignitor tube to provide a significant initial volume and projectile velocity.

To test this configuration an external control box was built. This box, when attached to the firing line of the gun, provided a means to control the ignition of the two ignitors; the igniter tube primer and the candelabra. Two sets of wires were fed from the cartridge to this control box. They are the second ignition squib leads and the movement sensor leads. The purpose of the external box was to direct the firing current. First the primary ignition element, the gun primer, was ignited. Then, after a specified delay, the second ignition element was ignited. One of the key safety concerns when developing this ignition system was the premature ignition of the second squib. If that squib were to fire before the main primer, or if the main primer were to misfire and the second squib was ignited, the resulting ignition could potentially over pressurize the gun. To insure this did not occur, a movement sensor was built into the cartridge and attached to the firing box. This sensor was designed to ensure the projectile translated a safe distance before the second ignitor could be fired. In the case of a primer misfire, the second squib would be disabled. This feature was rigorously tested in the 120 mm gun simulator before full gun testing.

Figure 7. The flexible candelabra ignitor system inserted into consolidated charges.

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The first full gun firings of the Smart Cartridge configuration were conducted in February 1999 and were an immediate success. The ability to "dial in" the cartridge performance, using the external control box, proved invaluable in meeting the TERM-KE performance. With the same consolidated charge configuration shown in Figure 5, the muzzle velocity requirements were exceeded at all temperatures, while the rocket case pressures were all at acceptable levels. Figure 8 shows representative pressure traces from each firing temperature. This clearly illustrates that by igniting the propellant earlier at the cold temperature, and later at the hot temperature, the performance can be maximized at all temperatures. Indeed, as is shown in Figure 9, the average velocity varied only 1% from cold to hot.

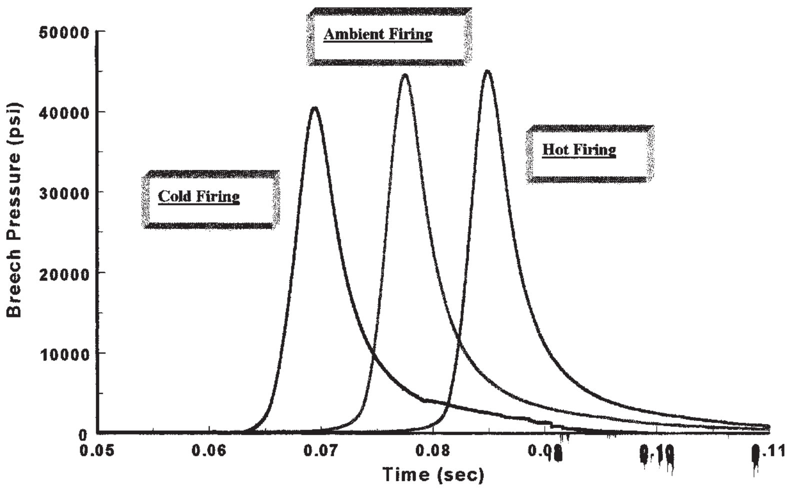

Figure 8. Pressure performance of the smart cartridge system.

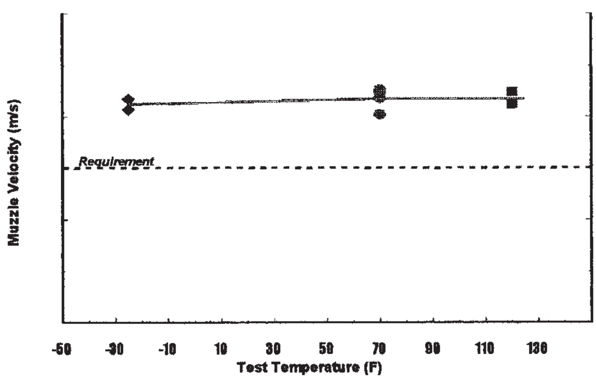

Figure 9. Muzzle velocity performance over temperature.

CURRENT AND FUTURE WORK

Current development efforts are focusing on the development of a tactical ignition system which will incorporate the functionality of the external system yet be fully enclosed within the 120 mm cartridge. This system will also include several features, which improve the system's performance, adaptability, and safety. Demonstration of this tactical TERM-KE gun propulsion system should occur in 2001. Continued development of the TERM-KE smart cartridge ignition system is planned, which will lead to further refinement of the concept. As a result, this technology will be poised for expanded deployment in applications which require unique and challenging ignition sequences.

ACKNOWLEDGEMENTS

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