THE DESIGN AND DEVELOPMENT OF A ROBOTICALLY EMPLACED HAND PACKED SHAPED CHARGE

S DeFisher, E Baker and I Wu[1]
J. Wu, A Richwald and MSG G Miller[2]

[1]U.S. Army RDECOM-ARDEC, Picatinny Arsenal, 07806-5000
[2]U.S. Army RDECOM-ARDEC EOD, Picatinny Arsenal, 07806-5000

In an effort to make the destruction of Improvised Explosive Devices (IEDs) safer the U.S. Army Armament Research, Development and Engineering Center warheads development personnel teamed with Explosive Ordnance Disposal (EOD) operators to develop, test, and field a hand packed, shaped charge capable of destroying buried IEDs. This device, designed to be employed via robot, provides EOD operators with a much higher level of safety than if they had to physically emplace the charges on IEDs themselves. This new device, loaded in the field with C-4 was designed to provide high performance at a low price. Initial testing was conducted to determine overburden penetration capability. After initial testing was completed, a series of modifications were made to enhance robotic handling, emplacement, and versatility. A final injection molded production body capable of destroying thickly cased buried IEDs was produced and disseminated to users after only eight months of effort. This has afforded EOD personnel an inexpensive solution for the dangerous and costly problem of IED destruction.

INTRODUCTION

Unexploded ordnance (UXO) and IEDs pose a serious threat to the EOD personnel assigned the task of destroying them. In an effort to make the job of destroying UXO and IEDs safer, Picatinny warheads development and EOD personnel teamed together to develop, test, and field a hand packed, robotically emplaced, shaped charge capable of defeating buried UXO and IEDs. The conditions under which IEDs are being encountered in the field in Iraq, often deeply buried under a soil and asphalt overburden, necessitated a higher performance device than any previously developed and currently in use for this purpose. This new device, loaded in the field with C-4 and capable of being detonated with a standard high output blasting cap via shock tube, was designed to penetrate and detonate buried IEDs. While the type of ordnance used in IEDs varies, one of the more difficult pieces of munition commonly encountered is the former Soviet 152mm artillery projectile. This projectile is known for having a thick case that is difficult for a shaped charge to penetrate when deeply buried beneath soil and asphalt. A series of tests were conducted to determine the suitability of various sizes of shaped charges, fired at various standoff distances, through different amounts of soil, asphalt, and steel overburden, to design a shaped charge that would safely detonate buried ordnance.

INITIAL TESTING

Upon beginning the program, EOD's primary requirement was that any new shaped charge design must be capable of penetrating a layer of asphalt and rocky soil before impacting and destroying a buried IED. It was the experience of EOD operators recently returned from the SWA theater, that was the type of overburden under which IEDs were commonly found. As a result of this rather vague criterion however, a couple of sizes of shaped charge devices needed to be initially tested.

In addition to the penetration requirement, a very real requirement which shaped the final geometry of this design was the need to be able to place the charge via remote controlled robot. Due to the extremely hazardous nature of IED location and disposal, remotely controlled robots are being used with increasing frequency to provide a safe standoff distance from which EOD operators can still go about the business of destroying ordnance. While this tremendously reduces the risk posed to EOD personnel, the complication that arises is that any device used by the robot must be capable of being manipulated with significantly less strength and dexterity, within appreciably constrained ranges of motion and articulation, than would be capable if it were hand emplaced by a human. As a result, a relatively light weight charge was called for. These design requirements necessitated features that otherwise not have been required for human emplacement.

Both sizes of charges were developed to be hand loaded with the explosive composition C-4. Although C-4 isn't as high performance as many pressed explosives more commonly used in shaped charges, it is readily available, used by EOD personnel on a daily basis, and has a known track record of being able to satisfactorily drive shaped charge liners. Furthermore, due to the fact that IEDs were being encountered on an almost daily basis, a solution was needed quickly. The fielding of a low technology copper lined shaped charge that could be locally loaded with explosive, rather than loaded at a loading plant and shipped in theater, would circumvent much of the traditional time consuming procedures required for the acquisition of typical ordnance, decreasing the time that the user was lacking a solution. Both sizes were also designed to accept standard high output blasting caps that EOD personnel commonly use.

The sizes of the shaped charge designs chosen for initial testing were 81 and 66 mm in diameter. Copper was chosen as the liner material as decent numbers of both liners had already been manufactured and were available. The 81 mm diameter liners were previously developed for generic insensitive munitions testing while the 66 mm diameter liners had been developed for a previously designed shoulder fired light anti-tank weapon (LAW) that never entered production. The bodies for each item were locally manufactured out of aluminum. The detonator holders were also locally manufactured out of either aluminum or acrylic. Figure 1 shows both types of unloaded rounds.

Figure 1 Unloaded 81 mm and 66mm prototypes

Field loading was accomplished by inserting the conical liner into the body, screwing down the liner retaining ring, and then stuffing C-4 in the back side around the liner. Since the liner to explosive interface is the most critical factor in shaped charge performance, care was taken to ensure the C-4 was in intimate contact with the liner. The technique which was found to produce the fewest gaps between the liner and explosive was to break off small pieces of C-4 from the larger blocks, knead them until soft, and then press the pieces around the liner by hand. Figure 2 shows prototypes of a partially loaded 81mm charge and a completely loaded 66mm charge ready for firing.

Figure 2 Partially loaded 81mm and 66mm prototypes

Both sizes of rounds were tested against overburden representative of that seen by EOD operators who had recently returned from in theater. It was hoped that at least one of the two rounds would be able to successfully penetrate the asphalt and rocky soil while still maintaining enough energy to penetrate a steel target below. Since the precise orientation and geometry of buried IEDs could not be ascertained a priori, buried target plates were used under the overburden for three out of four of the initial shots. An empty 105mm projectile was used as the target for the fourth and final test shot. Standoff distances of both 1 and 3 charge diameters (CDs) were used to ensure that a sufficient range of penetration capability would be tested. From the extensive body of work in the field of traditional anti-armor applications of shaped charges performance is well known to be a function of standoff distances. The reason for this is that given too little standoff, the jet has not had adequate time to form and to stretch to the maximum extent possible before being interfered with by the target. At distances that are too great, the charge has more than enough time to form and to stretch and in fact begins to particulate. When particulation occurs, the particles that form begin to drift off course and penetration drops off appreciably. The effect is that penetration is generally maximized at stand off distances greater than 3 charge diameters depending on the specific liner design.

While the penetration results were less precise than those commonly seen for pressed explosive anti-armor warheads, overall penetration depth was more than sufficient for the intended application. In all cases however, penetration was greater than required. In the fourth and final shot conducted against an empty 105mm projectile, the shaped charge jet penetrated through both sides of the round and into the ground beneath as seen in figure 3.

Figure 3 Initial larger design tested against an empty 105mm projectile

Since the smaller of the two charges penetrated a sufficient depth at a single CD of standoff, through a representative level of overburden, it was selected for further development. Although longer standoffs result in deeper penetration, it also forces the device to be longer, and as a result, much less stable and difficult to deploy via robot. In addition, the smaller device requires less C-4 making it at least somewhat more convenient to use in the field since less C-4 would have to be carried for loading.

SUBSEQUENT TESTING

After the initial round of testing, wherein it was determined that penetration performance should be great enough for the 66mm charge at 1 CD of standoff, a test was conducted against actual live 155 mm M107 artillery projectiles loaded with Composition B. Two 66mm shaped charge bodies were manufactured and loaded with C-4 explosive. A setup of the initial IED simulant and the overburden setup can be seen in figure 4 below.

Figure 4 Second round test against live IED simulant

In addition to the asphalt and rocky soil, a thick steel plate was placed on top of the round in the region that the jet would penetrate. This was done to simulate a scenario that would be more difficult for the shaped charge to penetrate than it would ever likely see during its use in theater. It was an over test conducted in an attempt to prove that any scenario which would be encountered in the field would be capable of being defeated. The results of the first test were a high order detonation with no large fragments remaining in the immediate vicinity.

The second of the two tests was designed to test the shaped charge to an even greater extent and as a result, even more asphalt, dirt, and intervening steel were used before the M107 artillery projectile. The results of this test were indicative of a low order detonation. Evidence of this could be found in the large fragments and pieces of unreacted high explosive (HE). Although this was not a high order detonation as seen previously, it was judged to be more than satisfactory as any IED that exhibited a similar reaction could reasonably be assumed to be inoperable or at least rendered safe by virtue of destruction of any firing mechanism. Evidence of the low order reaction, due to excessive overburden, can be seen in figure 5.

Figure 5 Large base fragment with unreacted Composition B

After the second round of testing demonstrated that the 66 mm charges would successfully detonate buried IEDs, a third round of testing was conducted with locally fabricated bodies. These bodies were fabricated on EOD’s Stereo Lithography Apparatus (SLA) machine and allowed the users to make a prototype and incorporate design features that they thought of while using inert shaped charged simulators with the robotic manipulator. One of the operators, for example, decided that in order to attack an IED from its side, or to be emplace the charge on a slope, a square top would better stop the device from rolling. Additionally, warheads development personnel felt that a more stable platform would be provided if the 1 CD of standoff were built into the body. This would make the charge more stable than if it had to be mated to a stand to provide equivalent standoff. These design features might not otherwise have been incorporated into the final design if EOD personnel not had the SLA machine on which to rapidly design and incorporate beneficial features discovered during testing.

In the interest of ensuring that none of their changes affected the penetration performance of the shaped charges, four bodies were printed and tested against steel to ensure equivalent performance. The results of this series of tests revealed that the penetration performance decreased appreciably from the prior scenarios when rocky soil overburden was used. The rocky soil portion of the overburden, which was absent from this test, was surmised to actually enhance the penetration performance of the round by providing a higher standoff, albeit through the use of a medium which proved to be relatively transparent to the shaped charge jet, allowing the jet to stretch to a more optimal length before impacting the intended target beneath.

An additional reason for the decreased penetration performance was believed to be the variable depth to which the detonator was inserted into the C-4. The distance from the initiator to the liner apex is critical to proper jet formation but was variable, subject to the depth to with which the operator inserted the detonator. As a result, the final design feature to be incorporated was the inclusion of a multi purpose tool. This tool, shaped much like a common engine valve, was used to compress the C-4 around the skirt of the liner where it was hard to reach by hand. More importantly however, when inserted through the detonator holder portion of the end cap, it was sized to provide a consistent depth for the insertion of the detonator so that the head height would not change from one shot to the next. Despite the decreased penetration performance, believed to have resulted from the lack of standoff and variable head height, the performance was judged to be sufficient to push forward and implement all the design features on an injection molded body.

Injection molding was chosen for the production of this body for several reasons. Fragmentation was a concern since these items have to be used in populated areas and minimal fragmentation, due to concerns over collateral damage, was desired. In addition, injection molding allows parts to be produced quickly, with more than sufficient accuracy for this application, and inexpensively when compared to machining.

In order to survive the temperature extremes munitions typically see in storage however, a high performance plastic was required. Lexan was chosen for its superior strength and durability under elevated temperatures.

As a final check, two final injection molded bodies were loaded and tested against live M107 rounds. Both shots resulted in high order detonations. Figure 6 shows the final design and test setup.

Figure 6 Final configuration setup

ROBOTIC DEVELOPMENT

Although this design effort focused on development of a dedicated shaped charge for use against IEDs, development efforts on the interface to the robotic manipulator proceeded in parallel and were the result of EOD personnel working in conjunction with contractors. The result of these efforts was the development of a disposable holder to which both the shock tube and the loaded shaped charge are attached to form a disposable charge assembly.

The way the assembly works is the operator readies the shaped charge at a remote location, a safe distance from the IED. He then attaches the shock tube spool to one end of the holder which he wires to the charge on the other end. He then moves the robot down range to the suspected IED which pays out the shock tube. The operator emplaces the assembly on the IED and releases it. The robot is then free to back away. The shaped charge is detonated when the robot has moved sufficiently far away. The holder was designed so that after it is released, the shock tube is sufficiently outside the width of the track so that the robot will not become entangled in the line. Figure 7 is a picture of one of the robots used for this type of work, with a loaded holder assembly.

Figure 7 Robot with remote emplacement assembly

SUMMARY

The disposal of UXO and IEDs is a dangerous job that has proven quite costly for U.S. military personnel. As a result, U.S. Army EOD operators have been forced to devise new methods of safely disposing of or destroying these devices. One method that they've devised is to remotely emplace a shaped charge via robot. This method allows the operator to stand a safe distance away from the IED while setting up a device capable of destroying buried explosive ordnance. Up until now however, although shaped charges existed for the purposed of destroying exposed explosive ordnance, none were available that could penetrate a significant amount of asphalt and soil overburden to detonate buried ordnance. Warheads development personnel, working in conjunction with EOD operators designed and developed a plastic bodied shaped charge that was not only sufficient to penetrate asphalt and rocky soil , setting off ordnance buried below, but one which was small and light enough to be deployed via a robotic manipulator.

This device, developed, tested and fielded within just 8 months, was designed to be loaded by the user in the field with Composition C-4. It incorporates a high performance copper liner, a minimally fragmenting plastic body with a built in stand off, a roll resistant lid, and a detonator seating tool. Used in conjunction with a recently designed emplacement assembly and one of a variety of remotely controlled robots, it represents a solution to the problem of destroying buried IEDs which did not previously exist.