**Reduced Energy Consumption Through
Projectile Based Excavation**

**Quarterly Technical Progress Report
07/01/02 - 09/30/02**

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Abstract.

The Projectile Based Excavation (ProjEX) program has as its goal, the reduction of energy required for production mining and secondary breakage through the use of a projectile based excavation system. It depends on the development of a low cost family of projectiles that will penetrate and break up different types of ore/rock and a low cost electric launch system. The electric launch system will eliminate the need for high cost propellant investigated for similar concepts in the past. This document reports on the progress made in the program during the past quarter. It reports on projectile development and the development of the electric launch system design.

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Technical Progress Report

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COR: Mr. Mike Mosser

1. Progress to date.

During the past quarter, field/quarry testing with the 60 mm system continued, but at a greatly reduced pace. An unfortunate accident (unrelated to this program, but involving a Lafarge subcontractor) and the Lafarge union negotiations caused a cessation of quarry testing during the quarter. Design of the electric launch system proceeded in a satisfactory manner and revealed that the cost of fabricating a prototype electric launch system was prohibitive for the current program funding level. As a result, an investigation of possible realignment of the program to focus on Secondary Breakage, rather than production mining was begun.

Field experiments - Experiments to determine the relative effectiveness of different projectile designs continued in the Lafarge Frederick Quarry. Difficult weather and equipment failure reduced the data collected in the most recent experiment campaign.

Experimental Apparatus – Experimental apparatus remained essentially unchanged. APTI continued work to get satisfactory performance from the high speed camera on loan from the University of Utah (Uof U). The camera was finally brought into operation during the 10 October test campaign.

The Drum Muffler Design continued to function properly and proved to satisfactorily reduce the acoustic signature from 132 dB to 114 dB. This is well within the MSHA limits for the Lafarge Frederick Quarry.

A Leica Total Station TCR 703 that was used to measure the crater volume had to be returned to Uof U. It has been replaced by a measurement system that, using a reference point, allows the estimation of the crater nominal cone volume.

A known reference point was chosen and marked. The distance to the aim point was measured. Following the shot, the diameter of the crater is measured and the distance from the reference point to the deepest point of the crater is taken. From that point the volume of a nominal cone is calculated and taken as the volume of rock removed from the face. This method allows a quick estimation of the crater volume. Speed in making this estimate is critical, to ensure multiple experiments can be performed in a single day.

Figure 1.1, included in the last report, shows the experiment setup and is included here for completeness. Not shown in the figure is the crushed stone that is placed at the rear of the gun mount to keep the gun in place during the shot. Without this addition, the gun will slide backward approximately 2 feet with each shot, necessitating repositioning, which is time consuming.

Figure 1.1. 60 mm launcher with drum muffler in place.

The velocimeter, also shown previously, was designed and fabricated by APTI and continued to function satisfactorily. It has survived several strikes from projectile components and rock from the mine face.

Figure 1.2. Velocimeter presented from two angles showing protection for circuitry on the left and breakwires at muzzle end in the image on the right.

Projectile designs – As mentioned in the last quarterly report, new designs have been developed that will survive high speed launch. These designs were fashioned after the

work performed by Physics International (PI) in the early 1970s, but include new concrete/grout products with increased strength. Figure 1.3 shows a typical design for the new projectiles.

Figure 1.3 Projectile design modification to improve ability to maintain integrity during high speed launch.

Wall thicknesses of 0.06", 0.125" and 0.23" have been fabricated from mild steel for testing. The PI designs used high strength Aluminum for the casing. The mild steel used here is far less costly, and of roughly the same tensile strength. The goal is to find a wall strength that will survive the acceleration in the gun barrel and release from the muzzle, but not result in large fragments in the muck.

A fully assembled 60 mm round of the new design is shown in Figure 1.4. The dark, striped covering on the projectile is the thin neoprene sabot.

Figure 1.4. Fully assembled 60 mm round ready to fire.

Figure 1.5 includes samples of the type fragments resulting from the rounds tested to date. These are small enough to pass through primary crushers and are easily deformed.

Figure 1.5. Mild steel fragments found following shots into limestone quarry wall.

Very few fragments have been found, suggesting that they are small enough to be lost (not identifiable during stirring of the muck and observation with the eye) in the muck created by the shots.

Electric Launch Discussion.

Unlike the projectile development components, the PFN components were unavailable from Army Research Laboratory and the development of the required 560 kJ PFN, from a zero base, will be costly (estimated at ~ \$70,000 for manpower and materials). Manpower estimates for the development of the laboratory electrical system alone are shown in Table 1-1. Component costs, amounting to ~ \$25,000 of this amount, were shown in last quarter's report. The repackaging of the laboratory system to make it suitable for field-testing will approximately double this cost.

Table 1-1. Estimates of manpower required to develop a 560 kJ laboratory PFN.

Component	engineer design hours	drafting hours	machining hours	assembly hours
capillary & chamber internals (10 sets)	16	24	120	
barrel support (recoil)	1	2	8	
target holder		4	16	
target tank assembly				4
targets (10)		1	16	
ignitron mounts	8	16	20	4
overvoltage spark gap	2	4	16	2
inductors	4	8	40	16

assemble capacitor array				6
busbar connections	4	8	40	32
power supply/control rack	4	2	8	16
current monitor	1	2	8	4
assembly management	16			
total	56	71	292	84

The redirection of the program towards Secondary Breakage does not eliminate the probable need for an electric launch system, but delays its development until the extent of a Secondary Breakage market can be determined.

For the 30 mm electric launch system, we have previously considered using existing ignitrons in parallel to meet the coulomb transfer needs of a capacitor bank to drive the steam gun. We now consider this inadvisable since the tubes would be used at their voltage limits. If one tube breaks down, it will carry many times its rated capacity, and the glass seal on the tube will likely fracture.* Using a large number of tubes increases the probability, per shot, of a spontaneous breakdown. Therefore, to lower risk and improve safety, we have modified the design to call for large capacity, 25 KV ignitrons and a 20 kV capacitor bank. Using our “large” (22 kV) capacitors, and building a 20 kV bank, affords us another increase in reliability, compared to using our “small” (10 kV) capacitors at full voltage.

The minimal cost, minimum effort approach to building the bank is to spread an insulating sheet on the laboratory floor and stand the capacitors on this sheet. Ground return bus bars, made from Aluminum bar stock, would tie all capacitor cases together. Hot bus bars, also Aluminum bar stock, would mount to G-10 fiberglass supports attached to the ground return bus bars in order to resist magnetic forces. The ignitrons would mount in Unistrut frames designed to support their pigtail connections against magnetic forces. The over voltage protection switch would also mount in a Unistrut frame. The inductors would be wound on plastic or fiberglass forms and jacketed in fiberglass to resist magnetic forces. The bus bar topology would avoid ground loops and minimize stray magnetic and electric fields in order to minimize EMP interference with the diagnostics, allowing the digitizers to function without a shielded room.

The existing I-beam, gun mount, and target shock absorber require minimal modification. However, a target plate holder must be manufactured to fit inside the target tank and hold the steel target plates in place.

The charging power supply, the control panel, the charge and dump relays, and the dump resistors would mount in one or two chassis racks (existing).

* Per discussions with Richardson Electronics

Hypothesis and Conclusions – The hypothesis to be further tested in the coming quarter is that an intact projectile will improve muck production significantly.

Results of the experiments conducted suggest that concrete with a strong aggregate and a steel (or other hard material) nose cone may result in a cost effective projectile-based excavation. The 60 mm experiments will continue in an effort to make that determination.

The electric launch system, for which there is a preliminary design, is the other factor that weighs heavily in the cost effectiveness equation. It has been determined, however, that the cost of performing a detailed design and the fabrication of the necessary prototype Pulse Forming Network (PFN) exceeds the resources available to this effort.

2. Problems encountered. As reported last quarter, increasing projectile velocity above ~ 1 km/sed has led to failure of the projectiles after leaving the launcher and before striking the target. Steps taken to date have not been successful in maintaining the integrity of the projectile at ~1.3 km/s. New projectile designs have been developed, however, the most recent quarry test campaign resulted in three successive misfires. The system will be analyzed thoroughly and the new projectile design will be tested in the next quarry campaign.

3. Plans for next reporting period. During the coming report period, plans call for the following.

- Realignment of the program to focus on Secondary Breakage.
- Development of a field test system for a 30 mm boulder engagement system.
- Identifying new industrial partners who will support the development of a Secondary Breakage system.

4. Prospects for future progress. With a realignment of the program to focus on Secondary Breakage, the prospects for future progress are excellent. We anticipate the modification of the on-hand 30 mm gun system and the acquisition of necessary propellant for quarry tests in the coming months and the initiation of field testing before the end of the coming quarter. The long range development of an electrical firing system may be possible in the coming Phase III, if initial field tests prove effective enough to move to the electrical launch design quickly.