LA-UR -93-2391

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TITLE: PHASE DETONATED SHOCK TUBE (PDST)

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SUBMITTED TO: XIV INTERNATIONAL CONFERENCE ON HIGH PRESSURE SCIENCE AND TECHNOLOGY AND 1993 TECHNICAL MEETING OF THE TOPICAL GROUP ON SHOCK COMPRESSION OF CONDENSED MATTER; JUNE 28-JULY 2, 1993; COLORADO SPRINGS, CO

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PHASE DETONATED SHOCK TUBE (PFST)*

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I. INTRODUCTION

The simple, cylindrically imploding and axially driven fast shock tube (FST) has been a basic component in our high velocity penetrator (HVP) program. It is a powerful device that is capable of delivering a directed and very high pressure output that we have successfully employed to drive hypervelocity projectiles. The FST is configured from a hollow, high explosive (HE) cylinder, a low density Styrofoam core, and a one point initiator at one end. A Mach stem is formed in the core as the forward propagating HE detonation wave interacts the reflected radial wave. By proper arrangement of HE length and diameters, a steady state Mach stem is readily achieved at the output end. Predetonation of HE is prevented by underdriving the Mach stem as it is being developed and this is most easily done by varying the foam density. The strength of the Mach stem is dependent on the effective energy transfer from the HE and this can be scaled geometrically. We have found this simple FST to be a powerful pressure multiplier. Typically, up to 1 Mbar output pressure can be obtained from this device. Further increase in the output pressure can be achieved by increasing the HE detonation velocity.

Over the last few years the FST has been fine tuned to drive a thin plate to very high velocity with an impulse per unit area of about 1 Mbar-μs/cm². Typically a 1 mm thick tantalum plate has been accelerated intact to [illegible] cm/μs under a loading pressure rate of several Mbar/μs. By making the plate [illegible] slightly convex at the loading side we have [illegible] accelerated it to almost 1.0 cm/μs. By placing a 1 mm layer of [illegible] as a buffer, a thin [illegible] titanium plate with an equivalent [illegible] has been accelerated to above 1.1 cm/μs. We have found the incorporation of a barrel at the end of the FST to be important. The confinement of the propellant gas by the barrel tends to accelerate the projectile to higher velocity. Furthermore, the standoff in the barrel between the plate and the FST allows the expanding gas to load more gently on the plate and thus reduces the loading pressure rate. A shockless acceleration is highly desirable to prevent the plate from being broken up prematurely. However, presence of a large standoff volume tends to introduce wall effects and generate serious perturbation from the not well understood, high pressure gas flow dynamics. We try to mitigate this difficulty by keeping the standoff distance as short as can be tolerated by experimental tests. In general we have found good agreement between the 2D numerical simulation and measurements. Even scaling tests appear to be satisfactory. A factor of three increase in the geometric dimensions of the FST, barrel, standoff, and plate yields similar results in both the calculations and experiments.

The desire to accelerate the plate above 1.1 cm/μs provides the impetus to develop a more advanced fast shock tube that will deliver a much higher output pressure. We decided to investigate a relatively simple but [illegible] phase detonation system (PDS) with fifty percent higher phase detonation velocity and a much [illegible] Mbar output. Our calculations show that the PDS [illegible] acceleration of a plate to about 1.[illegible] cm/μs can be achieved. The performance of the PDFST has been evaluated and the details are discussed below.

II. DESCRIPTION OF PHASE DETONATED FST

The phase detonated FST is shown in Figure 1a. The fast detonation velocity component of a [illegible] phase HE [illegible] is detonated on the left of the [illegible]

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*This work supported by the US Department of Energy.

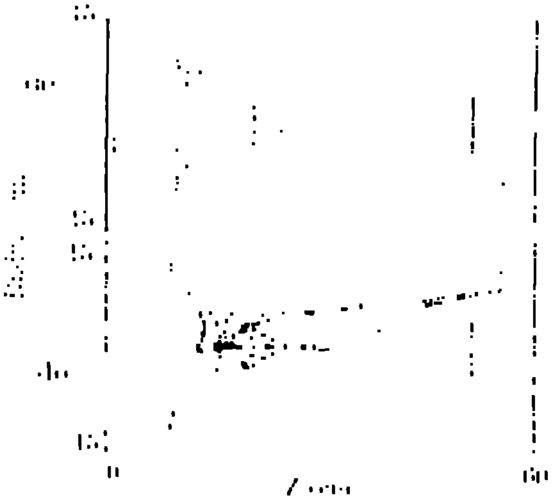

FIGURE [illegible]
Phase-detonated FSL with a diagram showing the setup and the Mach disk [illegible] plots

and then detonate the cylinder of Composition B-3 on the outside surface of the FSL. As its detonation proceeds to the right, a cylindrical shell of 304 stainless steel (SS) is propelled radially inward. It impinges on the conical surface of a 6061 aluminum phasing lens, the angle of which determines the phase velocity of the system (Figure [illegible]). The lens transmits a shock to a cylindrical shell of PBX 9501 explosive and detonates it at an axial velocity determined by the pha[illegible] [illegible]. An axial cylinder of Styrofoam is then shock compressed by this travelling detonation front resulting in a Mach disk travelling at the same phase velocity. It ultimately breaks out of the system at the right-hand face and causes the acceleration of a 304SS plate placed against that face or suspended in a 304SS barrel that rests against that face.

The purpose of the steel plate against the base of the PBX lens, the polyethylene washer against its periphery, and the polyethylene disk at the left face of the phasing lens are to prevent the predetonation of the PBX 9501 explosive before the shock from the collapsing 304SS cylinder detonates it. The plug of polyethylene on the left face of the Styrofoam results in a short run distance for the full diameter formation of the Mach disk.

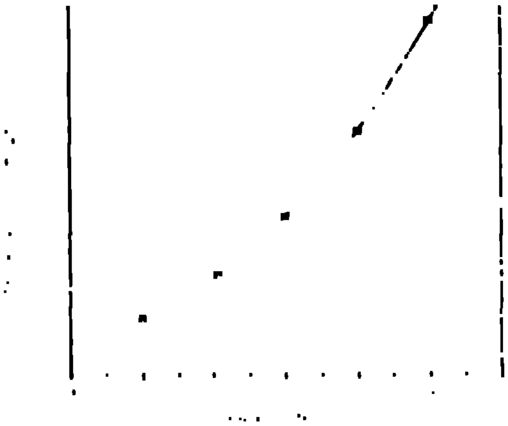

FIGURE [illegible]
Calculated phase [illegible] as a function of [illegible]

III. PHASE-DETONATION, MACH DISK PERFORMANCE

The hydrocode, MESA-2D, has been used to model the overall performance of the phase-detonated FSL. It is a 2D, Eulerian, second-order code that can handle multimaterial problems and can treat the programmed detonation of high explosives. The results shown here have been obtained using a Cray Y-MP computer.

The modeling of a phase-detonated FSL with a [illegible] is shown in Figure [illegible]. The incoming collapse of the 304SS cylinder onto the 6061 Al phasing lens, shock [illegible] in the [illegible] phase detonation of the PBX 9501 explosive and Mach disk formation. The angle of the phasing lens [illegible] and the resulting phase velocity of the PBX 9501 detonation front is [illegible], an increase of [illegible] over the normal detonation velocity of [illegible]. The shock velocity of the [illegible] in the Styrofoam is the same value of [illegible].

Three [illegible] experiments have been performed to measure the phase velocity in the [illegible] in Figure [illegible]. To accomplish this, twelve small-diameter coaxial cables were imbedded at equal [illegible] around an aluminum [illegible] that replaced the [illegible] [illegible] [illegible] axial grooves machined into the aluminum rod and then had their protruding outer conductors carefully scraped off, exposing the central coaxial conductor (Figure 3). As the phase detonation proceeded along the PBX 9501 explosive, the cables were shorted and through an interferometry circuit the position vs time data of the twelve cables was determined. The velocity was then extracted from the x-t data.

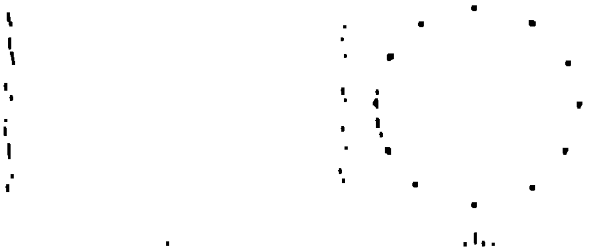

FIGURE 3
Side and end view of microwave interferometer probe used to determine phase velocity

A plot of the detonation velocity average of the channels is shown in Figure 4. The phase velocity is seen to be [illegible] cm/μs, which is acceptably close to the [illegible] velocity of [illegible] cm/μs. [illegible]

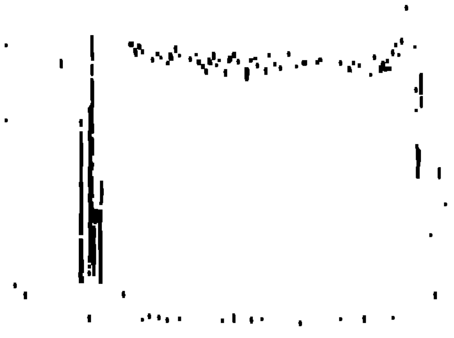

FIGURE 4
[illegible]

IV. PLATE-ACCELERATION PERFORMANCE

Because of the poor results obtained when trying to accelerate a plate down a barrel it was decided to attempt (with a vertical axis system) to accelerate a plate initially in contact with the shock tube face and having convex plate curvature toward the shock tube face as shown in Figure 5. The plate is 0.15 cm thick 304SS and for the two systems studied the radii of curvature of the plate faces against the shock tube were 11.3 cm and 5.72 cm. Hydrocalculations in these two systems are shown in overlays on Figure 5. The effect of decreasing the radius of curvature is evident in the greater consolidation, thickness, and increased forward bowing. The plate velocities are [illegible] and [illegible] cm/μs for the long and the short radius of curvature plates, respectively.

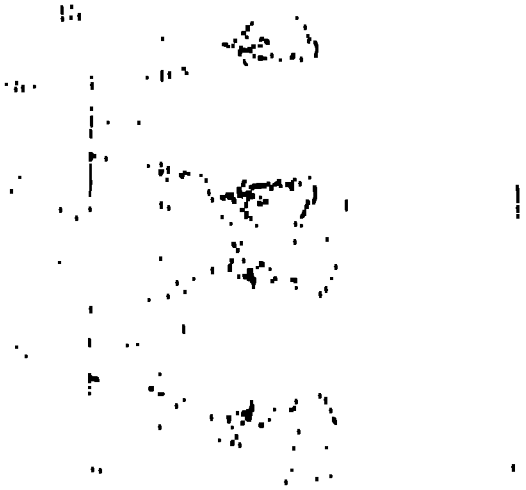

FIGURE 5
[illegible] of calculated plate contours at [illegible] after phase detonated [illegible] Radius of curvature of the plate [illegible] cm and [illegible] cm

Experiments were performed on shock tubes with the [illegible] radii of curvature machined on the plate [illegible] [illegible] the [illegible] and PBX 9501. [illegible]

The experimental setup for these shots is shown in Figure 6. The assemblies accelerated the plates vertically downward. The displacements of the plates at the X-ray times ([illegible] and 20.1 cm) were greater than the lateral displacements shown in the hydrocalculations (6.3 cm in both calculations) in order to protect the x-ray head and the film cassettes from blast and fragments.

The radiographic results for these shots are given in Figure 7. Only one exposure was obtained for shot 57-4296 because only one channel of the flash x-ray unit triggered. But a plate velocity was obtained for this shot by using information on initial motion time obtained from hydrocalculations and the earlier shot fired. The velocity of the plate in shot 57-4296 is 1.18 cm/μs and the velocity of the concave part of the tip in shot 57-4296 is 1.16 cm/μs.

The difference in the calculated and experimental plate contours for the plate with 11.37 cm radius of curvature (Figures 5a and 7a) is caused by early fracture of the plate at its periphery (not modeled by the hydrocode) reducing the driving pressure in that region and causing it to lag behind the plate center, which can be seen in Figure 7a. Although the same peripheral pressure drop occurs for the plate with the smaller radius of curvature, the convergence is enough to ensure that it holds forward and collapses [illegible] the [illegible] displacements [illegible] [illegible]. The plate [illegible] of this shot may be [illegible] to the [illegible] internal [illegible] after the [illegible]

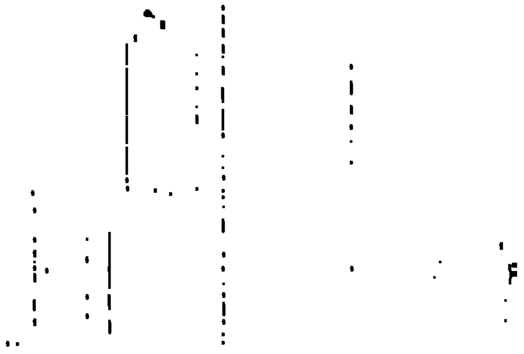

FIGURE 6
Experimental setup for shots [illegible] and 57-4296

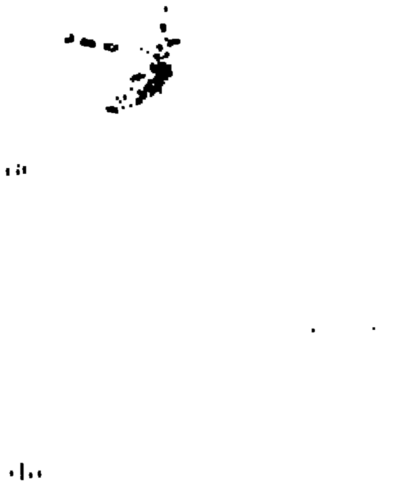

FIGURE 7
Radiograph of stainless steel plates moving to the right in (a) shot 57-4297 and (b) shot 57-4296. Over consolidation of plate in (b) can be seen to form a rod.

[illegible] are completed and the plate is [illegible]

V. CONCLUSIONS

Detonation of PBX 9404 at a phase velocity of [illegible] has been observed, and the detonation [illegible] was uniform at [illegible] positions around the inner cylindrical interface. A Mach disk in an axial [illegible] inside a cylinder within the explosive was formed and traveled at the same phase velocity. Precursor shocks [illegible] caused by the foam explosive interface were eliminated by firing the shot vertically and placing a [illegible] in the interface gap. A radius of curvature of 11.37 cm on the driving face of a [illegible] plate in contact with the foam HE face of a [illegible] tube produced plate convergence during acceleration and allowed the plate to reach a velocity of 1.1 cm/μs. The [illegible] of the plate indicate it may have melted. Arrangement [illegible] with a [illegible] of appropriate [illegible] [illegible] plate [illegible]