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USE OF Z-PINCH SOURCES FOR HIGH-PRESSURE SHOCK WAVE EXPERIMENTS

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Recent developments have demonstrated the use of pulsed power for producing intense radiation sources (z-pinches) that can drive planar shock waves in samples with spatial dimensions significantly larger than possible with other radiation sources. In this paper, we will discuss the use of z-pinch sources for shock wave studies at multi-Mbar pressures. Experimental plans to use the technique for absolute shock Hugoniot measurements and with accuracies comparable to that obtained with gun launchers are discussed.

Introduction

Shock wave techniques have long been a principal tool for determining the high pressure (EOS) of materials in regimes inaccessible by other methods (1). A variety of shock wave techniques have been developed for producing well-controlled shock planar shock waves to study dynamic material response. For ultra-high EOS measurements, underground nuclear tests (2) have been used to produce shock wave pressures of about 3000 Mbar. Recently, there has been considerable interest in using energy deposition techniques for shock wave measurements. Evans et al. (3) have developed direct deposition laser techniques using impedance matching to produce shock waves in copper to pressures of about 20 Mbar. Baumung et al. (4) are developing proton beam techniques to launch thin flyer plates to high velocities. Most recently, Cauble et al. have developed a technique for making absolute measurements of the equations of state of low atomic number materials in regimes of extremely high pressure (5).

We are developing methods for making precise time-resolved measurements of planar shock waves produced by Z pinch techniques. This technique uses imploding metal plasma produced by self-magnetic fields to produce high temperature x-ray environments in hohlraum enclosures to drive shock waves through an ablation process. Previous experiments have demonstrated that planar shock waves can be produced with this approach. (6). Stepped aluminum samples, ranging in thickness from 100 μm to 300 μm thickness and with lateral dimensions of about 9 mm in diameter, are used as samples. VISAR interferometry is used to measure particle velocity behind the shock wave and fiber optic breakout "pins" are used to determine shock velocity between prescribed steps in the target. The combined diagnostics provide an absolute measurement of the shock Hugoniot and also allow EOS information on the isentropic unloading response.

Experimental Technique

The target, Figure 1a, consists of an aluminum disk top hat design. A Lithium Fluoride (LiF) window, 3 mm thick with a diffused, vacuum deposited aluminum mirror is bonded to the top

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hat. The target is mounted to a secondary hohlraum, as shown in Figure 1b.

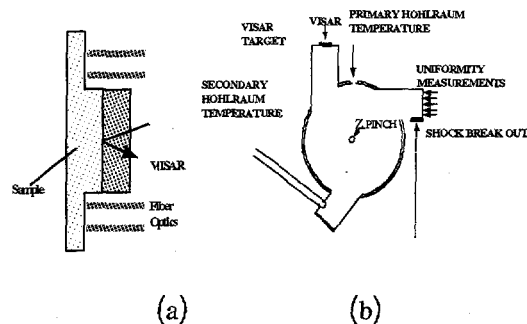


Figure 1. Experimental technique for shock wave studies on Z. (a) target configuration, (b) hohlraum design.

Additional secondary hohlraums are used to detect shock planarity and breakout. Fiber optic probes are used on the first step to measure shock arrival. The shock breakout probes consist of an active and return fiber set approximately 0.5 mm off the surface. The reduction of light due to shock arrival is coupled through the return fiber to a streak camera. A narrow band-pass (1 nm FWHM) filter centered on the laser line frequency was inserted in the return fiber prior to the streak camera to reduce the effect of fiber fluoresce. The alignment of the fibers to a spectral surface is very difficult and not dependable. Because of this, a diffuse surface is used to reflect light into the return fiber. Additional techniques such as a multifiber bundle are also being considered.

A miniature fiber optics probe has been developed to focus the incident VISAR beam on the LiF target interface and to collect the reflected diffuse light for use in the VISAR. The probe has an efficiency of 10% - 12% and has been used successfully for VISAR measurements.

All VISAR diagnostics were tested in the radiation environment of the Z accelerator. The experiments consisted of irradiating 200 micron core, radiation hardened fiber within 100 mm of the z-pinch load. This resulted in a fluorescence signal that routinely saturated the detectors. Fiber darkening was tested by passing an argon ion laser beam down the fiber and observing the decrease in transmission during and after the radiation dose. Both effects were mitigated by installing a 1.2 nm FWHM spectral filter centered at 514.5 nm, which reduced the fluorescence signal by factors of 100-1000.

Other tests examined the use of LiF shock windows and miniature glass lenses as components of VISAR probes. The LiF windows darkened in about 20 ns to a transmissivity of 60% and recovered in ~ 400 ns, while the lenses darkened at about 100 ns after z pinch.

Optical fibers provide a convenient means to transmit diagnostic signals in experiments utilizing a high-energy pulsed power source such as PBFA-Z. A concern is the temporal dispersion that occurs in optical waveguides. This phenomenon must be considered and characterized in any experimental seeking < 1ns resolution.

Neglecting material dispersion or absorption, the maximum pulse spread t_d is given by (10):

$$t_d = \frac{z}{c} n_{co} \left\{ \frac{n_{co}}{n_{cl}} - 1 \right\}$$

where z is fiber length, c is the speed of light, and n_{co} and n_{cl} represent the refractive indices of the fiber core and cladding, respectively. For a multimode fused silica fiber this relation yields a maximum pulse spread of 56 ps/m. Observed values are likely to fall closer to the r.m.s. width (11) which is $\sim t_d / \sqrt{12}$; a spread of 16 ps/m.

The ray dispersion equations suggest that intensity-based measurements can be made at temporal resolutions approaching 100 ps provided that fiber lengths are limited to ~10 meters. More stringent constraints exist in applications involving velocity interferometry, where the fiber dispersion must be considered in relation to the desired optical time delay. In tests with an ORVIS, we found that accurate profiles can be recorded when the signal is coupled through short fiber sections; coupling through a long fiber significantly degrades performance.

The fringe records in Figure 2 were generated by laser-accelerated flyer plates launched under nearly identical driving conditions. Fig. 2a exhibits the typical response of a conventional, open-beam ORVIS using, in this case, an optical time delay of 228 ps (corresponding to a velocity-per-fringe constant of $1.09 \text{ km}\cdot\text{s}^{-1}$). In Fig. 2b, light reflected from the accelerating target was coupled through a 41.5-m-long, 200- μm -diameter fiber. This element introduces a nominal r.m.s. pulse spread of 0.67 ns. With this relatively large dispersion (three times longer than the interferometer delay time), ORVIS was clearly unable to record the correct fringe motion, completely "losing" the appropriate fringe positions at onset of flyer motion and in a later time period (as well as apparently generating anomalously low slopes at other times). The deleterious dispersion effects were found to be even more pronounced in witness plate tests producing particle velocity pulses $<6 \text{ ns}$ in duration. Experiments to define the limits on fiber strength relative to the fringe constant parameter of the interferometer are in progress.

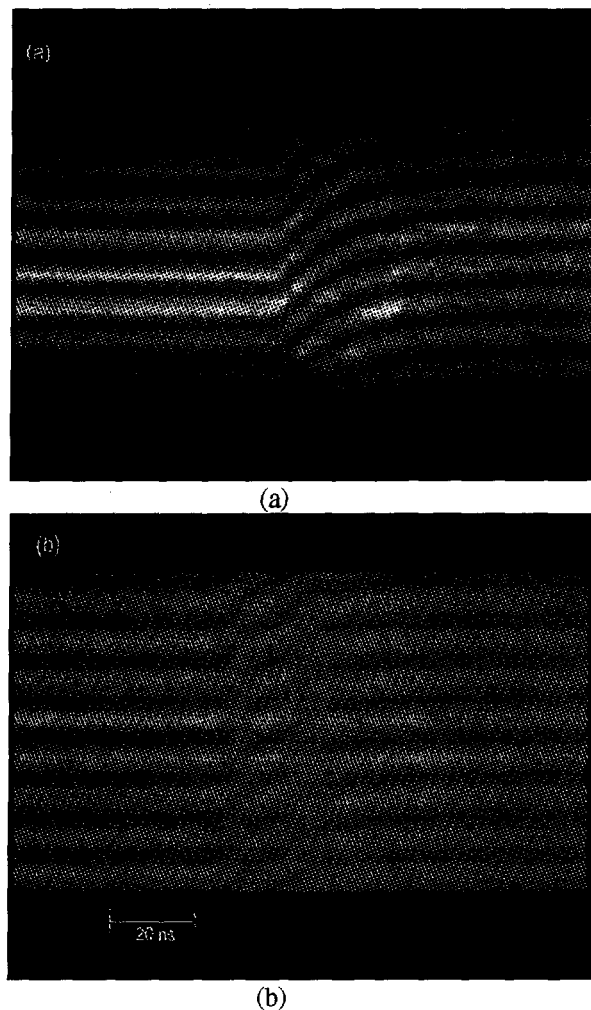


Fig. 2. ORVIS velocity-time records of laser-driven flyers. Time proceeds from left to right. Fringe Constant is $1.09 \text{ km}\cdot\text{s}^{-1}$. (a) open-beam ORVIS; (b) fiber optic coupled signal.

Numerical Simulations

We simulated the ablation pressures in various materials using a 15 ns wide trapezoidal radiation source (Planckian) in the ALEGRA (7) code. This code utilizes an implementation of the SPARTAN SPN package developed by Mo-

rel and Hall (8,9). The calculations were run in 1-D Cartesian geometry. Sixty energy groups over the range to 10 keV were used. Materials studied included CH, Al, Ti, and W, using SESAME EOS tables and opacity determined by XSN. Peak temperatures for the assumed radiation pulse were chosen over the interval of 50 to 200 eV, which is characteristic of the secondary radiation hohlraums.

The purpose of this study was to investigate ablation pressure scaling with atomic number of the target. Two types of calculations were undertaken. First, direct illumination of the targets was performed. Second, calculations were done with a CH ablator. For direct illumination, we found that ablation pressures increased more rapidly with peak source temperature than expected for tungsten and titanium.

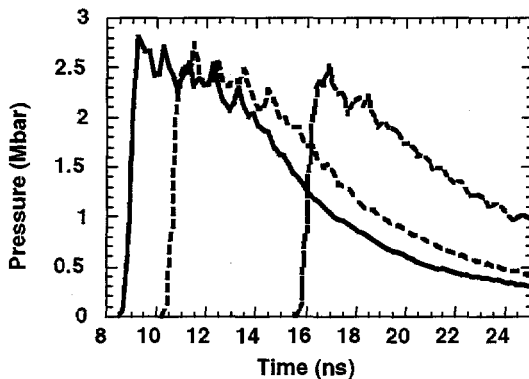


FIGURE 3. Pressure profiles in aluminum for a 100 eV drive at distances of 75, 100 and 175 μm .

For the lower Z materials, our results were in reasonable agreement with both Dukart's calculations and analytic approximations to the scaling behavior. Numerical calculations of pressure wave profiles expected in aluminum for a 100 - eV x-ray temperature are shown in Figure 3 (11).

Summary

In summary, we are developing a new diagnostic using z pinch sources for producing high pressure shock waves. VISAR measurements of particle velocity and fiber optic measurements of particle velocity and shock speed are used for absolute EOS measurements. Preliminary data obtained with the technique are encouraging.

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