Use of z-Pinch Techniques for Equation of State Applications

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Abstract

A principal goal of the shock physics program at Sandia is to establish a capability to make accurate equation of state (EOS) measurements on the Z pulsed radiation source. The Z accelerator is a source of intense x-ray radiation, which can be used to drive ablative shocks for EOS studies. With this source, ablative multi-Mbar shocks can be produced to study materials over the range of interest to both weapons and ICF physics programs. In developing the capability to diagnose these types of studies on Z, techniques commonly used in conventional impact generated experiments were implemented. The primary diagnostic presently being used for this work is velocity interferometry, VISAR, which not only provides Hugoniot particle velocity measurements, but also measurements of non-shock EOS measurements, such as isentropic compression. In addition to VISAR capability, methods for measuring shock velocity have also been developed for shock studies on Z. When used in conjunction with the Rankine-Hugoniot jump conditions, material response at high temperatures and pressures can be inferred.

Radiation in the Z accelerator is produced when approximately 18 MA are passed through a cylindrical wire array typically 20 to 50 mm in diameter and 10 to 20 mm in height. 200-300 wires with initial diameters on the order of 8 to 20 micron form, upon application of the current, a plasma shell, which is magnetically imploded until it collapses and stagnates on axis, forming a dense plasma emitter in the shape of a column, referred to as a " z pinch".

The initial wire array and subsequent plasma pinch are confined within a metallic can, referred to as a primary hohlraum, which serves as both a current return path and a reflective surface to contain the radiation. Attached to openings in the primary hohlraum wall are smaller tubes referred to as secondaries. Multiple secondaries can be fielded on most experiments, which are the typical location for mounting EOS samples. A standard experimental configuration of a primary with three secondaries is shown in Figure 1.

In this configuration, the secondary S1 contains two separate VISAR probes for making velocity measurements at different material thicknesses. By correlating the resulting velocity profiles in time, a measurement of shock velocity can be determined. In addition, the velocity profiles provide the Hugoniot particle velocity after the records were impedance-matched.

Secondaries S2 and S3 provide measurements of shock velocity using laser light reflected from steps. As the shock arrives at each of these surfaces, the surface reflectivity significantly decreases, which causes a sharp drop in return light. The shock velocity can be inferred from shock arrival at different steps.

The z-pinch technique is particularly useful for producing high amplitude shock waves for EOS applications. An alternative approach for using Z is to produce shockless loading directly with the magnetic pressure in the accelerator. The concept is shown in Fig. 2a. During operation

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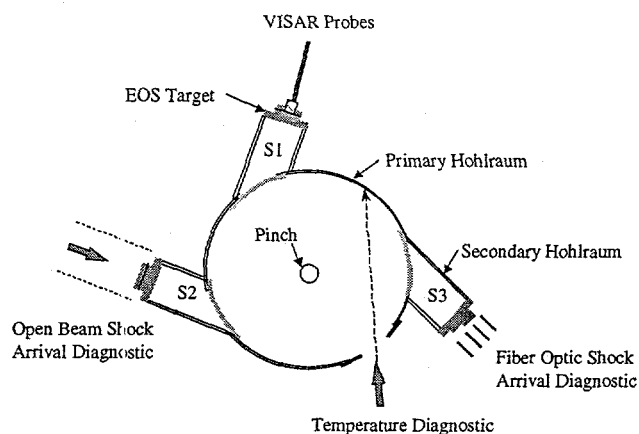produced from the best available original
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FIGURE 1: A standard experimental configuration for performing equation of state studies on the Z accelerator using ablatively driven shocks.
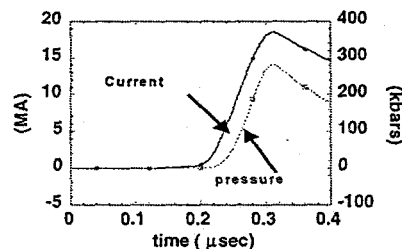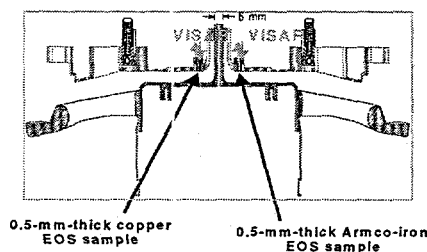

Figure 2. (a) Configuration for producing shockless loading in the accelerator. (b) Predicted current and pressure histories to planar disks.

About 18 Ma of current is developed between an anode and cathode. In Figure 2a, the electrodes are directly connected without an imploding load. Magnetic pressure is produced in the gap region, which can be used to shocklessly load the surface of a specimen over a time duration of approximately 100 ns. The representative current and magnetic history predictions are shown in Fig. 2b.

In the present experiments, specimens of copper and iron, approximately 0.5 mm thick and 3 mm in diameter were placed in the anode at a radius of 13.85 mm from center and directly exposed to the magnetic pressure in the gap. Since the current converges in this geometry, a minor gradient in pressure is produced over the face of the sample. This was not a major limitation in establishing feasibility of the technique, although future experiments will minimize this effect. The skin depth of current and field in the Fe and Cu disks was estimated with an analytic model of non-linear flux diffusion to be about 0.41 mm and 0.12 mm, respectively.

Recent data are presented in Fig. 3. Shock wave profiles were obtained on aluminum shocked to 1-3 Mbar using the z-pinch technique. Both shock velocity through stepped Al targets and the

particle velocity on an Al specimen were measured. Figure 3a shows the resulting particle velocity profile on one experiment; this can be combined with measured shock velocity to infer a Hugoniot data point.

We have also used magnetic compression to demonstrate feasibility for performing isentropic compression on Z to about 300 kbar. The resulting free surface particle velocity obtained on iron is shown in Fig. 3b, which shows elastic yielding, the 130 kbar hcp-bcc crystallographic phase transition, and compression in the high pressure phase. The quality of the experimental records indicates that it should be possible to obtain accurate measured isentropes.
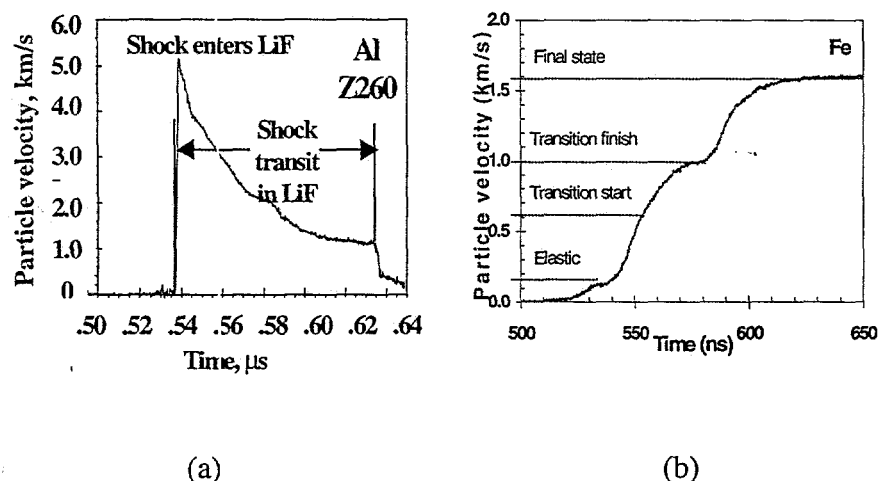

(a)   (b)

Figure 3.   (a) u_p obtained on a 0.1 mm thick Al sample shocked to 1.6 Mbar.
(b) u_p obtained on 0.5 mm Fe for isentropic loading to 300 kbar.

We will present equation of state data on aluminum and beryllium obtained with the z-pinch technique to shock pressures of about 3 Mbar. Isentropic loading data will be presented for iron compressed to several hundred kbar. These data represent the first accurate shock EOS data obtained with z-pinch techniques and the first isentropic compression data obtained on iron in the high pressure region. The iron data illustrate the effects of slower rates on the kinetics of the hcp-bcc phase transition beginning at about 130 kbar.