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## Z-Pinch Drivers for Shock Physics Research\*

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### Abstract

The recent development of Z pinch drivers for producing intense radiation environments enables study of physical and mechanical properties of condensed materials in regimes previously inaccessible in the laboratory. With Z pinch radiation sources, it is possible to subject mm-sized samples to planar compressions of a few Mbar. Time-resolved velocity interferometry was used to perform the first shock loading and unloading profiles in Al and Be for ablative driven shocks to 3 Mbar and the first isentropic loading of iron specimens to 300 kbar.

### Introduction

A principal goal of our shock physics program is to establish a capability to make accurate equation of state measurements on the Z pulsed radiation source. The Z accelerator is a source of intense 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, [1] 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. The next section discusses the basic approach for conducting EOS experiments on Z for both shock loading and isentropic compression on the Z accelerator.

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## Experimental Configuration

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. On the order of 8 to 20 micron wires in diameter forms a plasma shell upon application of the current, 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" [2].

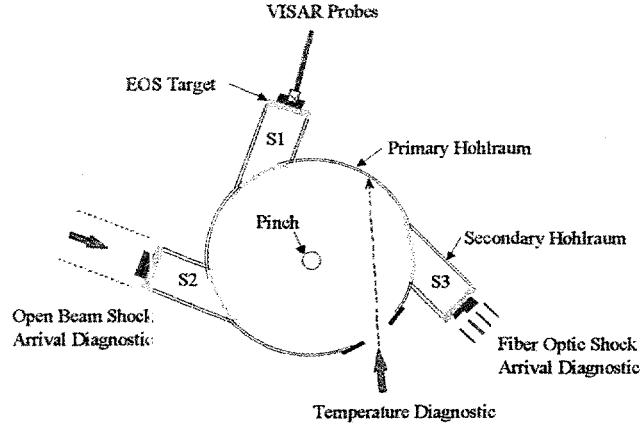


FIGURE 1: A standard experimental configuration for performing equation of state studies on the Z accelerator using ablation-driven shocks.

The initial wire array and subsequent plasma pinch are confined within a metallic can which serves as both a current return path and a reflective surface to contain the radiation in a primary hohlraum. 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 attached for EOS studies is shown in Figure 1.

In this configuration, the secondary S1 contains two separate VISAR samples 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 [3].

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 step heights.

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, about 18 MA of

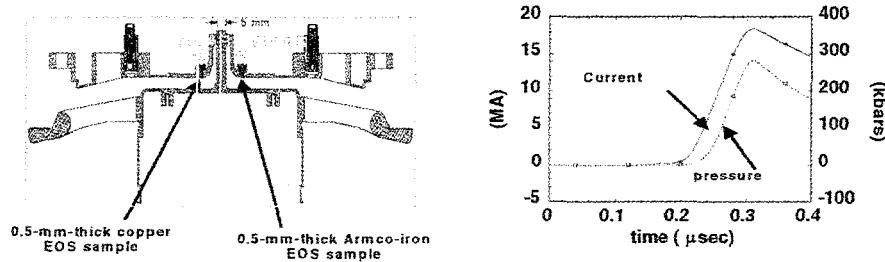


Figure 2. (a) Configuration for producing shockless loading in the accelerator.  
 (b) Applied current and pressure histories to planar disks.

current is developed between an anode and cathode. In Figure 2a, the electrodes are directly connected without a inductive load. Magnetic pressure is produced in the gap region, which can be used to produce pressure on the surface of a specimen over a time duration. The current and magnetic histories shown in Fig. 2b are representative of the loading conditions.

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 0.15 mm, respectively.

Recent data obtained with both Z pinch driven shocks and magnetically driven pressure are presented in Fig. 3. Detailed discussion of these results will be published elsewhere [4]. 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. The resulting magnetic pressure was 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 EOS data on Z.

## Summary

In summary, the Z accelerator was used to determine shock velocity and particle velocity in specimens ablatively shocked to Mbar. Preliminary data acquired on Al and Be indicate that it should be possible to obtain Hugoniot data to several Mbar. Improvements to achieve this goal include (1) development of more uniform pressure loading over specimens, (2) implementation of a constant pressure for several ns, and (3) refinement of the diagnostics for 1-2% accuracy.

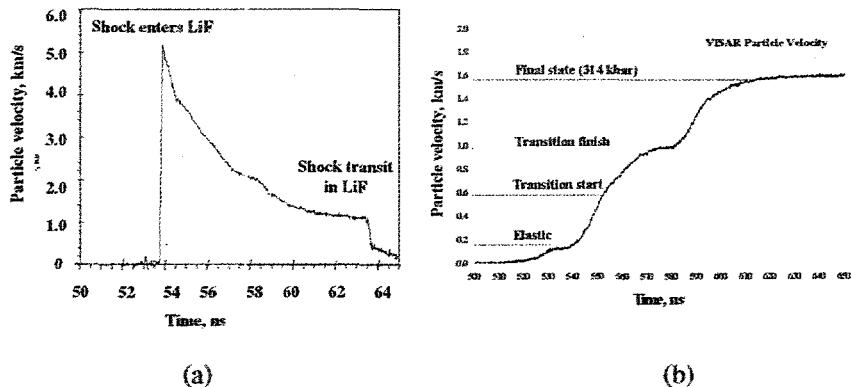


Figure 3. (a) Particle velocity profile obtained on a 0.1 mm thick aluminum sample shocked to about 1.6 Mbar with a Z pinch. (b) free surface velocity obtained on a 0.5 mm thick iron specimen during isentropic compression to 300 kbar.

We also demonstrated the ability to perform isentropic compression experiments on Z using a direct short between the anode and cathode that produces magnetic pressure to shocklessly load specimens. The feasibility of this concept was demonstrated on specimens of Fe and Cu with smoothly increasing magnetic pressure to 300 kbar over 100 ns. The resulting particle velocity profiles agree qualitatively with previous shock wave data on iron.

## References

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