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Damaged Surface Hydrodynamics (DSH) Flash Report

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Purpose

In an effort to understand the complex hydrodynamic flow present when a non-ideal (or damaged) surface between a dense, solid-state metal impinges on a light, gas in converging geometry, two DSH experiments have been conducted at the LANL LANSCE pRad facility utilizing magnetic drive from the Precision High Energy-density Liner Implosion eXperiment (PHELIX) pulsed power capacitor bank. Here a tungsten power coated target aluminum cylinder was filled with inert gas (Ar/Xe). An outer aluminum cylinder is magnetically accelerated and impacts the target shock launching the powder into the gas and compressing the cylinder until such time as the increase in gas pressure causes stagnation. Each experiment is imaged with a 21-frame proton radiography movie where gas shocks, powder distribution, and target cylinder are clearly visible. These two experiments complement the DSH-0 experiment from FY14 where the target cylinder was evacuated as a control case. A schematic of the DSH concept as well as a 1D MHD calculation is shown in Figure 1.

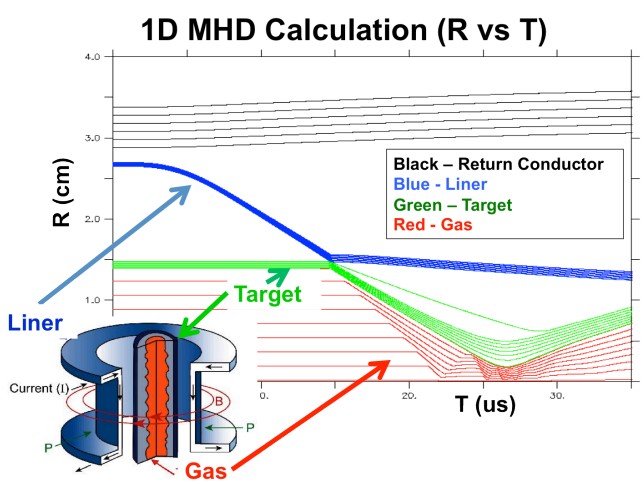

Figure 1. Schematic and preshot calculation of DSH experiment.

The DSH concept addresses two questions:

- How do particles, born on a (shocked) surface transport in the increasingly dense gas background of a cylindrically converging system? What is their distribution in space, velocity and time?
- Which, if any, currently explored models can describe transport in this simple, well-controlled example.

- Fluid Instability Turbulence Models (BHR) (continuum)
- Particle generation and transport models tracking particle-fluid interaction (no particle/particle)
- Emerging granular-fluid models (with particle/particle)

Experiment Objectives

1. Conduct two DSH experiments driven by PHELIX.
2. Observe and diagnose the shock-launched tungsten powder transport from a solid cylindrical surface into an inert gas with proton radiography.
3. Produce pressure driven turn-around of the target.
4. Investigate the effect of gas species (Ar vs Xe) on target dynamics and powder transport.
5. Provide data to validate ejecta and mix models in ASC Hydro codes.

Experimental Method

PHELIX is a portable capacitor bank designed specifically to interface with the LANL proton radiography diagnostic at LANSCE. It is capable of storing 340 kJ of electricity in 68 μF at 100 kV. It can discharge a 5 MA peak, 5-10 us wide current pulse into static low inductance load. PHELIX utilizes a unique toroidal, air-core transformer with multi-filar feeds and a 4:1 winding ratio to efficiently amplify output from the capacitors and deliver it to a central experimental cassette load. Figure 2 shows PHELIX, the transformer, and a DSH cassette load.

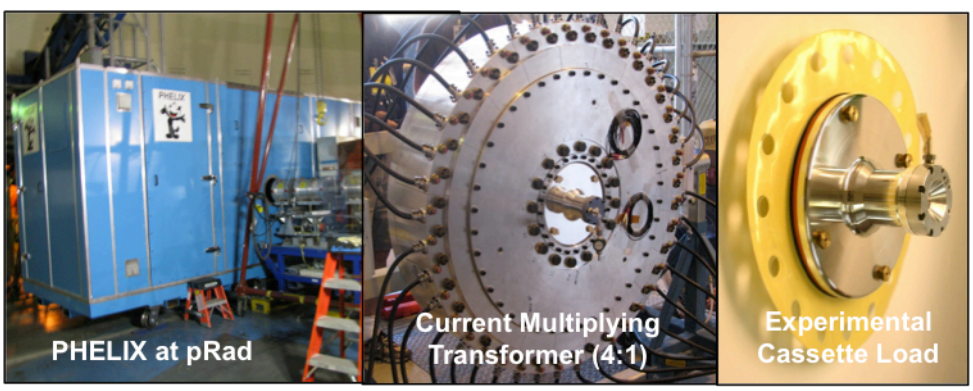

Figure 2. The PHELIX capacitor bank at pRad, transformer, and experimental load.

The PHELIX capacitor bank is used to magnetically accelerate a thin wall, cylindrical Al liner (R_0 = 2.73 cm, dr = 0.5 mm) to ~1 km/s. It symmetrically impacts a thin wall Al target (R_0 = 1.50 cm, dr = 1.0 mm) and shock launches a coating (δr = 0.1 mm) of micron size tungsten powder (ρ_{avg} ~ 8 g/cc) into ~ 9 atm of inert gas (Ar or Xe). A cut-away view of the cassette load is shown in Figure 3. The transverse length of the target ~3.00 cm.

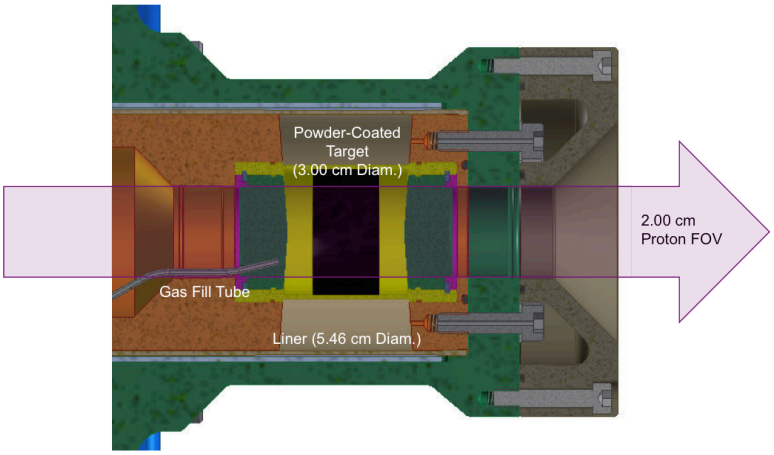

Figure 3. Cut-away view of the DSH cassette load. The proton radiography beam is axially aligned with the load to image the dynamics implosion.

The PHELIX has been fully integrated into normal operation as a driver for dynamic experiments at LANL proton radiography facility. There, up to 21 high-resolution axially aligned images with high dynamic range can be obtained in a single experiment. Motion blue is minimized by ~60 nS framing time in each image.

Results

The current delivered to the load is precisely measured by an optical Faraday rotation technique. A polarized laser beam traverses a field aligned twisted fiber. The pulsed field causes rotation of polarization angle that can be measured and recorded. The current is then reconstructed from the Verdet constant for the fiber and the laser wavelength. The current profiles for DSH-1 and 2 are shown in Figure 4. The dynamic nature of the DSH reduces I_{peak} ~ 3.5 MA. However, note that the current profiles are nearly identical demonstrating that PHELIX is a highly reliable and reproducible driver.

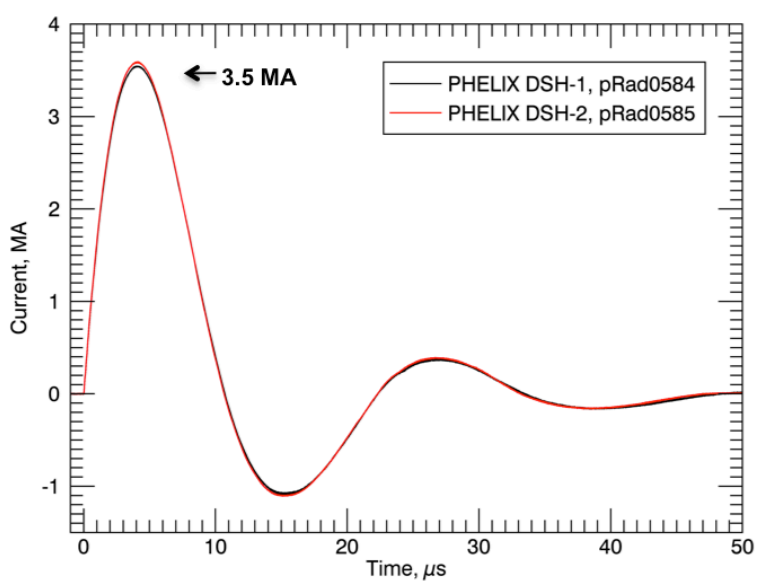

Figure 4. Measured load current for DSH-1 and 2.

Twenty-one image movies of both DSH-1 and 2 were obtained. Each image is corrected for non-uniform beam profile. For brevity only a single frame from each experiment is shown in Figure 5. Darker areas indicate higher areal density.

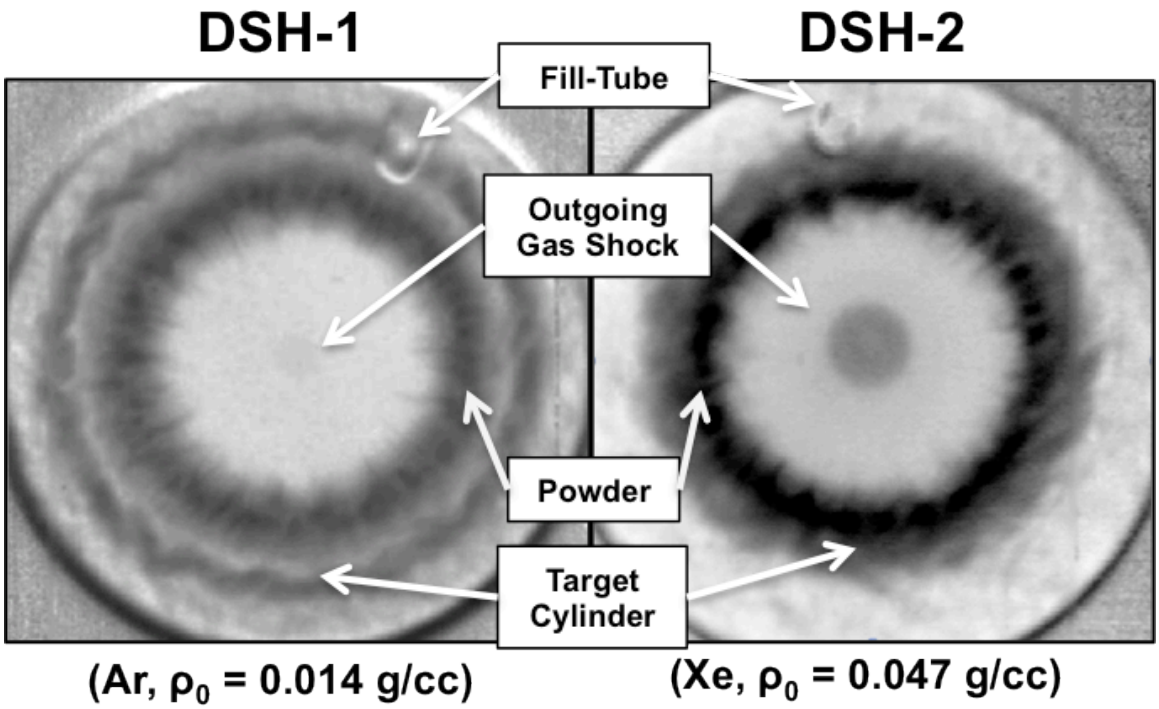

Figure 5. Sample proton radiography images of DSH-1 and 2.

Clearly visible in both images are:

- A stationary gas fill tube
- A circular shock wave within the gas. Prior to these images the initial shock has radially converged on axis; shown is the radially expanding shock. The Xe provides a larger density discontinuity and thus better contrast.
- A circular tungsten powder layer with high mode number (n > 20) aziumuthal spatial modulation. These radial spikes were also observed in DSH-0 with a vacuum center. Pre-shot densitometry showed uniform powder coating. Dynamic, transverse flash X-ray has shown the modulations are axially correlated over 0.5-1.0 cm.
- A circular target cylinder. In DSH-1 there is a gap between the target and powder, while in DSH-2 no gap is observed. This indicates that the higher density Xe provides a stronger drag force on the micron size tungsten particles.

Though not shown in this brief report, the proton radiography clearly shows the stagnation of the outer surface of the target layer and re-expansion.

Summary

Two DSH experiments were conducted in October of FY 2015 in support of the Science Campaign-1 L2 Milestone. They were both driven by the PHELIX capacitor bank and

utilized the LANL LANSCE proton radiography facility as the primary diagnostic. 100% Data return was achieved on both experiments including 21 frame pRad movies. All objectives of the experiments were met. Currently, the data set is being analyzed and calculations are being performed to try and understand the observed complex distribution of the powder layer.