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One-and-Two-dimensional Simulations of Liner Performance at Atlas Parameters

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Abstract

We report results of one-and-two-dimensional MHD simulations of an imploding heavy liner in Z-pinch geometry. The driving current has a pulse shape and peak current characteristic of the Atlas pulsed-power facility being constructed at Los Alamos National Laboratory. One-dimensional simulations of heavy composite liners driven by 30 MA currents can achieve velocities on the order of 14 km/sec. Used to impact a tungsten target, the liner produces shock pressures of approximately fourteen megabars. The first 2-D simulations of imploding liners driven at Atlas current parameters are also described. These simulations have focused on the interaction of the liner with the glide planes, and the effect of realistic surface perturbations on the dynamics of the pinch. It is found that the former interaction does not seriously affect the inner liner surface. Results from the second problem indicate that a surface perturbation having amplitude as small as 0.2 μm can have a significant effect on the implosion dynamics.

Introduction

Los Alamos National Laboratory is in the construction phase for one of the world's highest-current pulsed power facilities. In response to DOE needs to ensure the safety and reliability of US nuclear weapons during a time of no nuclear testing, the Atlas facility (i) will provide a unique environment for fielding above ground experiments in support of the Stockpile Stewardship Program.

Atlas will operate at a peak current between 27 MA – 32 MA with a pulse rise time of approximately 4 μs. Three to five megajoules of kinetic energy will be delivered to a 45-gram liner in a time of 7.5 μs. A typical liner will be a four-centimeter high and be made of pure aluminum, or an outer Al shell with an inner shell of tungsten. At impact the liner will have a velocity on the order of 14 km/s. One set of experiments will be devoted toward performing shock compression experiments to measure material equations-of-state (EOS) in the multi-megabar pressure regime. A composite liner combines the attractive
attributes of the two materials without deleteriously impacting the implosion velocity.

1-D Results

The 1-D simulations were performed using a Lagrangian MHD code that solves a set of equations representing the dynamics of the liner coupled with the pulsed power system, the latter being represented as a lumped circuit. Material strength is included in the model. Resistivities and pressures are obtained from SESAME tables, or, in some cases, analytic models.

The inner radii for the tungsten sleeves using the two drive currents are shown in fig. 1. Figure 2 shows the peak pressure profiles that are generated within the impactor - target assembly. These pressures remain steady for 20 ns, and are in excellent agreement with analytic results.

2-D Results

Two-dimensional effects can adversely affect the one-dimensional results. For example, surface perturbations resulting from the machining process, can provide a seed for growing Rayleigh-Taylor instabilities. Figure 3 shows the wall thickness variation of a high precision aluminum liner. Over the 44 mm length the liner thickness varies by 0.2 μm. In the simulations this variation is imposed as a perturbation of the outer liner surface of the liner. Both aluminum and composite liners were modeled. The former simulations included an eight-degree tungsten glide plane. For the composite Al/W liner only the middle one centimeter of the perturbation was simulated, and the glide plane was removed.

Figures 4a and 4b show snapshots of the instability in the aluminum liner. Near target impact time the inner surface of the aluminum is distorted along its length. For the composite liner the increased strength of the tungsten sleeve should ameliorate this undesirable feature.

Composite liner simulations are difficult to perform because of the number of zones needed to accurately model the strength of the tungsten sleeve. We use eight radial cells to resolve 100 μm of tungsten. This translates into an excessively large number of cells for the problem, and consequently limits the run time to < 5 μs. The liner has an inner radius of 3.7 cm, with a 1 mm thick aluminum shell surrounding the tungsten. Figures 5a and 5b show the instability development. Figure 6 shows the distortion of the upper surface of the tungsten sleeve at 4.75 μs. This distortion is measured at thirteen times, and fit to a log scale to obtain a linear growth rate of 4.1 μs⁻¹.

References:

Fig. 1: Inner liner radii for the two currents. Current profile is shown for timing comparison.

Fig. 2: Target pressures for two drives.

Fig. 3: Smoothed portion of the perturbation employed in the simulation.

Fig. 4a: RT instability of Al liner at 5.5 µs.
Fig. 4b: Nonlinear RT instability near impact

Fig. 5a: RT instability at 3.5 μs in composite liner

Fig. 5b: RT instability at 4.75 μs showing distortion of tungsten sleeve

Fig. 6: Perturbation of upper surface of tungsten sleeve at 4.75 μs.