Simulations of Radiatively-Driven Implosions on the PBFA-Z Facility

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Abstract. We have performed two-dimensional calculations of the implosions of thin-walled aluminum cylinders driven by a source of radiation. The source is generated by the stagnation of an imploding plasma liner on to a foam target (dynamic hohlraum or flying radiation case) in the PBFA-Z facility at Sandia National Laboratory in Albuquerque, New Mexico. Both Lagrangian and Eulerian codes are used for the simulations of the compression of the shell by the ablatively-driven main shock.

Introduction

The implosion of a cylindrical wire array (driven by the energy from the discharge of a capacitor bank) has been used to generate a source of x-rays at Sandia National Laboratory^(1, 2). The radiation is produced by the dynamic hohlraum (DH) when the plasma from the wires stagnates. Measurements have shown that peak radiation temperatures within the hohlraum reach 150 eV, with the full-width-at-half-maximum of the radiation pulse being about 5 ns. The x-ray source can be used to study the coupling of radiation to different targets, shock-driven mixing of materials in high-energy-density regimes and fusion experiments.

The dynamic hohlraum and the aluminum target are shown in figure 1. The foam hohlraum is coated with a thin layer of tungsten with a linear density of 2 mg/cm. The foam itself is polyethylene with a density of 20 mg/cc. Coaxial to the hohlraum is the aluminum target with a wall thickness of 200 microns. The inner radius of

FIGURE 1. (a) The implosion of a cylindrical wire array drives a plasma radially inwards onto a foam target. Stagnation of the plasma on the foam generates the radiation for a variety of experiments. (b) In the simulations, a cylindrical aluminum shell is placed coaxially within the hohlraum.

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the shell is 0.10 cm and the cavity is filled with CH foam which also has a density of 20 mg/cc. A Lagrangian radiation-hydrodynamic code was used to simulate the coupling of the radiation to the aluminum and the subsequent generation of an ablatively-driven shock through the material. The plasma is magnetically unstable and perturbations associated with the vaporization of the wires will grow during the implosion, producing a classical spike and bubble structure prior to pinch. These instabilities affect the quality of the radiation front produced during the pinch and of the subsequent shock formed in the target. Therefore, an Eulerian magnetohydrodynamic (MHD) code has been used to investigate these effects. The second section describes the results of the Lagrangian calculations. The simulations of an initially perturbed plasma done with the Eulerian MHD code are given in the third section. The last section contains the summary and conclusions drawn from the calculations as well as directions for future research. Both codes use a three-temperature gray diffusion radiation package.

Lagrangian Calculations

The driving source for the Lagrangian calculations is simulated by the impact of a tungsten plasma on the foam hohlraum with an initial velocity of 0.053 cm/ns (figure (2)). The tungsten plasma is initially at a temperature of 5.0 ev and has a density of 4.0 mg/cc. As the tungsten plasma encounters the foam cylinder (which is coated with a thin layer of tungsten with a linear density of 2 mg/cm) it stagnates, creating a source of radiation that fills the hohlraum. The peak radiation temperature inside the hohlraum reaches 155 ev in this model. The electron temperature initially lags behind the radiation temperature. However, temperature equilibration occurs in just under 3 ns. Magneto-hydrodynamic effects have been ignored in the Lagrangian

FIGURE 2. In the Lagrangian calculations, the radiation source is simulated by the deceleration of a tungsten plasma (4 mg/cc) which strikes the thin tungsten coating on the foam cylinder with an initial radial velocity of 0.053 cm/ns. As the plasma (which is at a temperature of 5.0 ev) stagnates, the generation of radiation begins to occur.

FIGURE 3. (a) Variations of densities with radial grid spacing in the cylinder at different times. (b) Variations of pressures in the aluminum as functions of radial grid spacing at different times.

calculations. The radiation within the hohlraum couples to the outer layers of aluminum, causing them to ablate. This drives a shock in the opposite direction through the aluminum. The ablation velocity reaches a peak of 0.012 cm/ns after which the interface begins to decelerate. The passage of the shock through the aluminum has the effect of compressing the cold material in front of it to densities of ~ 8 -10 g/cc or about three times normal density (figure (3a)). The pressures in this region rise to around 25 megabars (figure (3b)). The mean ion charge in the wake of the shock is 11, so the aluminum atoms are stripped of electrons down to the k-shell. Both the radiation and electron temperatures are about 125 eV and the aluminum density in the ablated region drops to around 0.1 g/cc.

Eulerian Calculations

The Eulerian calculations used an initially perturbed model that was calibrated to the implosion of a tungsten wire array which had an initial radius of 2.0 cm and a mass of 4.0 mg. The capacitor bank was represented by a single equivalent circuit loop with a time-dependent voltage source $V(t)$, resistance $R=120\text{ m}\Omega$ and inductance $L=10.24\text{ nH}$ to the load. The tungsten plasma is shown in figure (4) at 212 ns after current delivery to the load. A central cylindrical foam cushion with a density of 20 mg/cc is also represented in the figure. The density contours in the tungsten plasma produced by the wire array are shown and range from 10^{-6} to 10^{-2} g/cc. The leading edge of the plasma has several low-density high-velocity features which may or may not be artifacts of the way in which the calculation was done. The vertical lines at 0.75 cm and 1.0 cm indicate the boundaries for a refined radiative implosion calculation.

The refined calculations for the radiatively-driven MHD implosion of the target are begun at 225 ns after current delivery to the load. This time is taken to be the zero time for the results presented here. The stagnation of the perturbed tungsten plasma on the foam cushion generates x-rays which are absorbed by the outer layers of the

FIGURE 4. The implosion of the tungsten plasma formed by the wire array is shown. The density contours in the plasma range from 10^{-6} to 10^{-2} g/cc. The vertical lines show the "slice" of the initial mesh that is used for the calculation of the radiation coupling to a central target.

aluminum shell. Peak radiation temperatures inside the hohlraum reach 140 eV. The electron temperatures lag behind the radiation temperatures for about 3 ns. The peak densities and pressures are comparable to those in the Lagrangian calculations, but the detailed shapes of the curves are quite different. This may be due to the different driving conditions for the two sets of calculations, the presence of instabilities in the Eulerian model as well as to slightly different equation-of-state and opacity tables used in the two cases. Despite the advanced state of instability growth in the tungsten plasma evident in figure (4), the radiation front produced by impact with the foam cushion was found to be quite smooth. Furthermore, the radiatively-driven shock in the target was found to be nearly uniform in the axial direction (apart from damage associated with the low-density, high-velocity small-scale features). Preliminary results indicate that the latter features, if real, may pose a serious problem for applications experiments. However, if they are not real, or if they can be suppressed, the resulting radiation drive and shock front are insensitive to the large-scale instabilities that arise during the implosion.

Summary

Results from the two-dimensional unperturbed Lagrangian and perturbed Eulerian calculations confirm that radiation generated in the dynamic hohlraum reaches peak temperatures of around 150 eV. The x-ray source has been used in the present calculations to implode a hollow cylindrical aluminum target. The ablation of the outer aluminum layers due to the absorption of radiation drives a convergent shock into the target. The shock strength is calculated to be around 30 megabars and, as a result, the aluminum is compressed to about 2.5 to 3 times normal density.

Future calculations will include a common definition of a radiation source for both the Lagrangian and the Eulerian calculations. A Monte-Carlo photonics package will be used in order to gain an improved understanding of the radiation transport within the dynamic hohlraum. The formation of the high-velocity low-density features in the tungsten plasma that were seen in the Eulerian calculations will be studied in more detail in order to determine their origin. Finally, experimental data are needed to determine whether or not these features actually exist.

References

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