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Current initiation in low-density foam z-pinch plasmas.

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Low density agar and aerogel foams were tested as z-pinch loads on the SATURN accelerator. In these first experiments, we studied the initial plasma conditions by measuring the visible emission at early times with a framing camera and 1-D imaging. At later time, near the stagnation when the plasma is hotter, x-ray imaging and spectral diagnostics were used to characterize the plasma. Filamentation and arcing at the current contacts was observed. None of the implosions were uniform along the z-axis. The prime causes of these problems are believed to be the electrode contacts and the current return configuration and these are solvable. Periodic phenomena consistent with the formation of instabilities were observed on one shot, not on others, implying that there may be a way of controlling instabilities in the pinch. Many of the issues involving current initiation may be solvable. Solutions are discussed.

DISCLAIMER

I. Introduction

The z-pinch targets discussed in this paper are important to the z-pinch physic program and the inertial confinement fusion program at Sandia National Laboratories. The targets are of interest to the z-pinch program because calculations indicate that solid targets are more stable than thin shell targets(such as wire arrays or foils).[1,2] They may lead to brighter and tighter pinches. The ICF application of z-pinches has been considered largely through the use of deuterium(or ultimately DT) pinches.[3] These targets also have the potential for creating a hohlraum[4] that could be used to drive an inertial confinement fusion capsule. [5] In this z-pinch fusion scenario the foam outer surface would carry the current through a high-z layer at the surface of the foam. As the current increases the magnetic pressure implodes the foam and high-z layer which then becomes more opaque and forms the hohlraum wall. The compressing mass and radiation field inside the hohlraum then compress a fusion capsule inside. The wall of the capsule ablates as the hohlraum collapses, helping to maintain and shape the hohlraum environment following a cold adiabat.[4]

These were our first experiments to study solid foam implosions on Saturn.[6] The purpose of these experiments was to identify the factors important to uniform pinch initiation and observe the effects of pinch initiation on the late-time behavior of the plasma. We do not have the tools to model the early time behavior. For this reason we designed the experiment to around the hardware that was used previously on the gaspuff experiments and attempted to determine its adequacy for these experiments. We used UV flashboards, a gold (as conductor) coating on the target surface, and a current prepulse in our attempt to initiate the targets uniformly.

We fielded two instruments new to Saturn, a visible framing camera and a visible or x-ray imaging streak system to look at early time visible emission. The results from these are presented in papers by Lazier[7] and Muron[8]. The analysis of the results from these measurements show that there was filamentation and non-uniform emission from all of these targets. Some of the targets were much more uniform than others; this implies there is some ability to control the pinch. In the paper by Antolak[9], this proceedings, generic uniformity effects and features of the targets are discussed. We don't have space to show each targets profile, however, we only used targets that had azimuthally symmetric features. This means that some of the targets had a slight hourglass profile. The results of spectroscopic measurements and the modeling of the spectra are discussed in two other papers by Nash[10] and MacFarlane[11]. In this paper, we discuss the results of the x-ray imaging and interpret the causes and effects of the non-uniformity's.

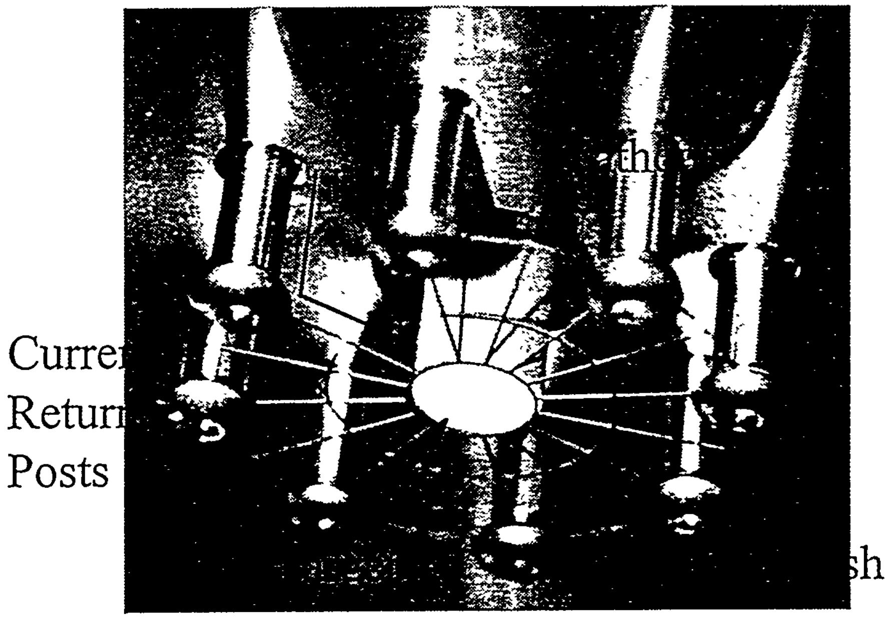

Fig. 1. Photograph of Agar target installed in z-pinch diode.

II The Targets and the Matrix of Shots

These targets were right circular cylinders of 1 cm outer dimensions (1 cm diameter x 1 cm long). Three of the targets were annular with a 9 mm inner diameter. We used a current return configuration used previously with gaspuff implosions.[12] This configuration, shown in Fig. 1, allowed good diagnostic access from the sides and the top. However, diagnostic access was adversely affected by the wires of the current return which were between the targets and the instrumentation.

Table 1. Shot descriptions and machine parameters.

Shot	Density (mg/cc)	Material	Coating	Shape	Machine Setup *	Mass
2249	5	Aerogel	--	Solid	no FB/PPS	3.9

2250	5	Aerogel	--	Solid	FB/PPS	3.9
2251	10	Agar	70Å PdAu	Annulus	FB/PPS	1.6
2252	10	Agar	--	Annulus	FB/PPS	1.6
2254	10	Agar	1200Å PdAu	Solid	FB/PPS	7.8
2255	10	Agar	2000Å PdAu	Annulus	FB/PPS	1.6
2256	7	Aerogel	2000Å Au	Solid	FB/ no PPS	5.5
2257	7	Aerogel	--	Solid	FB/ no PPS	5.5
2258	3	Aerogel	1200Å Au	Solid	FB/ no PPS	2.4

*- FB=UV flashboards, PPS=pre-pulse suppression

We ordered 20 5mg/cc aerogel targets to perform the initiation study, however, there were problems with their geometry[13] and only two were acceptable for use. In order to complete the experiment to study the effects of current initiation we used targets of different densities and different coating types. We considered this acceptable because the initiation is insensitive to the density. Coating of PdAu were used initially because of the insensitivity of these coatings to oxidation. Unfortunately, the aerogel targets did not survive the coating process and we switched to Au coatings

Conventional wisdom, obtained through the literature and discussions with personnel in the z-pinch program suggested that any or all of the following methodologies could result in a uniform plasma at the surface of the foam targets, resulting in a uniform current sheath: UV flashboards, electrons transported to the target from the magnetically insulated transmission lines, a thin conducting coating on the target surface, presence or absence of a prepulse (low current observed well below the main current pulse) and contact impedance at the anode or cathode connections. The target and machine configurations utilized in this series allowed us to observe effects of each of these variables.

Results

Improved coupling to the machine is apparent based on the ratio of the amount of emitted radiation to the calculated kinetic energy. This is shown where we have plotted the ratio of the x-ray yield as measured against the calculated kinetic energy transferred to the load with SCREAMER[14]. This is an attempt to remove target to target variations (such as mass, or annular versus cylindrical geometry) when comparing coupling efficiency to the accelerator.

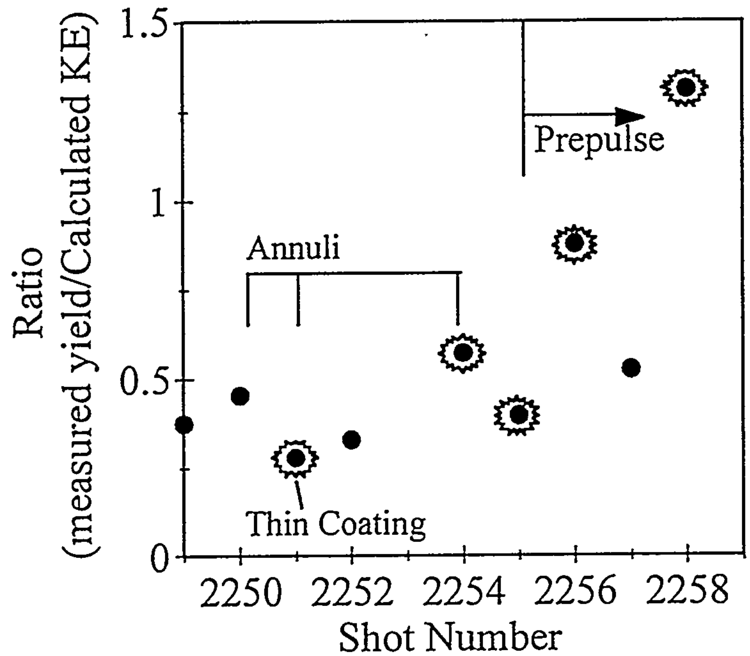

Fig. 2. Ratio of the measured x-ray yield to the calculated kinetic energy in the target.

The best coupling to the machine was obtained on shot 2258, a 3 mg/cc foam coated with 1200 Å of Au where 180 $\pm$ 60 kJ was emitted. The machine was operated with flashboards, and prepulse. A 100 ps gated framing camera image taken at peak power is shown in figure 3. The image shows a small amount of emission from the anode mesh region, with a bright implosion feature from the bulk of the foam. The lineouts oin the figure show a horizontal FWHM of 2 mm and a non-uniform vertical emission profile along the pinch. The radial convergence is acceptable for some z-pinch inertial confinement fusion target designs. The axial variation is undesirable.

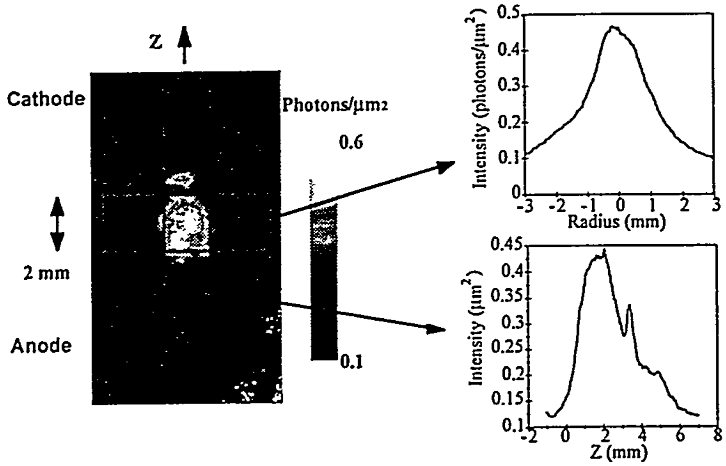

Fig. 3. A 100 ps gated x-ray frame at peak power. The two lineouts are of the radial and axial emission.

On these shots the emission features appeared first on the anode portion of the target and moved toward the cathode. This is shown in Fig. 4, where three frames, roughly 12 ns apart illustrate the motion. The intensity of the frames is normalized to the peak intensity in the frame. This apparent motion may be due to the anode jet (See Macfarlane (these proceedings, where the spectrum implies a low density hot plasma and Muron, where the jet is observed at early time), where the plasma in the jet is material removed from the anode side of the target allowing the near anode material to pinch earlier in time.

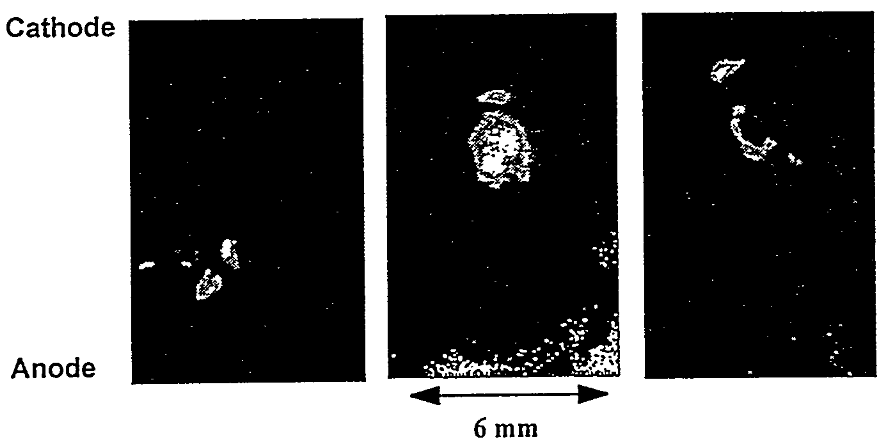

Fig. 4. Three gated frames, separated by 12 ns, with the center frame at peak intensity from shot 2258. These images show the emission moving from the anode to the cathode.

The current prepulse has the effect of reducing the bulk of the early time emission. This is shown in Fig. 5, where the current and x-ray diode (XRD) traces from two high mass targets are compared. The x-ray emission from the shot with a prepulse peaks at 75 ns, which is close to the calculated implosion time of 74 ns. The calculated implosion time for the target without prepulse is 80 ns. Clearly the emission occurs at early times when there is no prepulse. On all the shots without prepulse similar features are observed, including multiple peaks in the x-ray emission (see Nash, these proceedings).

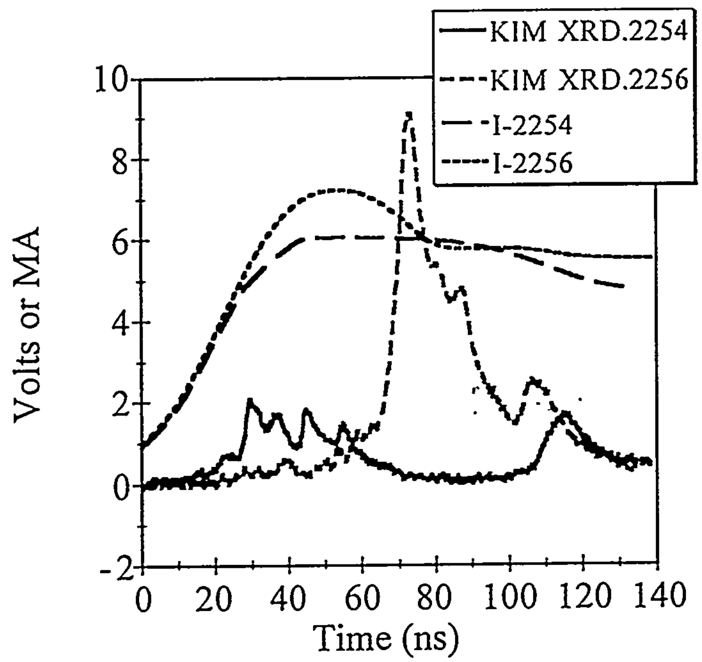

Fig. 5. Comparison of the current and Kimfol filtered XRD (200-280 eV window) traces from shots 2254 and 2256.

Increasing the early time conductivity, with the target coating and prepulse, is the most important factor in obtaining good coupling to the machine. This is illustrated in another way by observation of the time-integrated frames of shots 2250 and 2258, as shown in figure 6. For shot 2250 most of the emission comes from either the anode region or the cathode, whereas in the image of shot 2258 most of the emission comes from the body of the foam target. No implosion feature is observed in shot 2250.

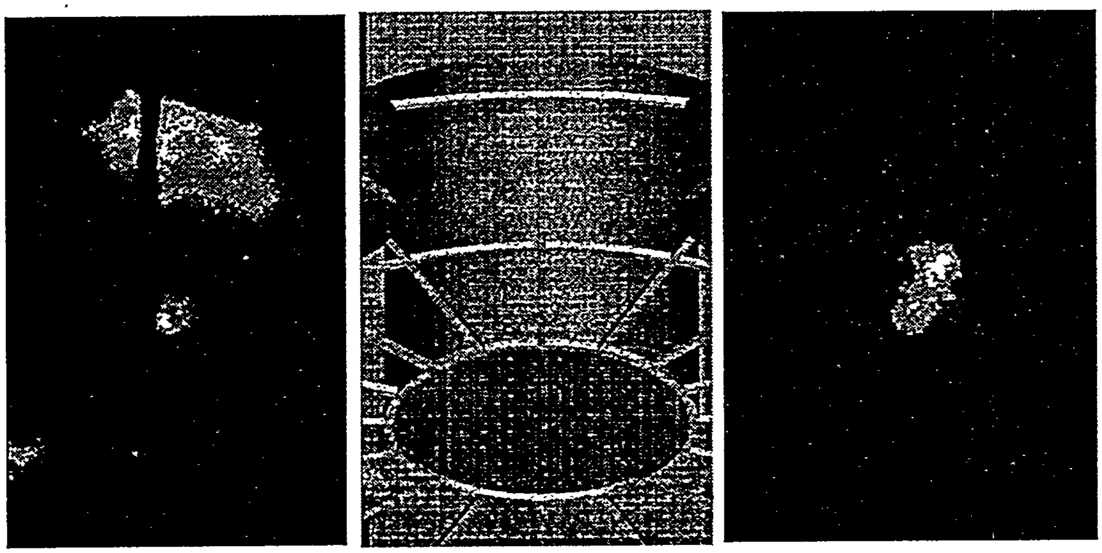

Fig. 6. The left figure is a time-integrated frame image of shot 2250, the center image is a rendition of the target as viewed through the line-of-sight, and the right image is the time-integrated frame of shot 2258.

The emission also shows signs of instability in the implosions, see Fig. 7. In the figure there is a lot of emission from the anode and below, as part of this jet out the target bottom, but from this target there is also emission from the main portion of the target. This emission shows periodic features that is evidence for instabilities in the pinch.

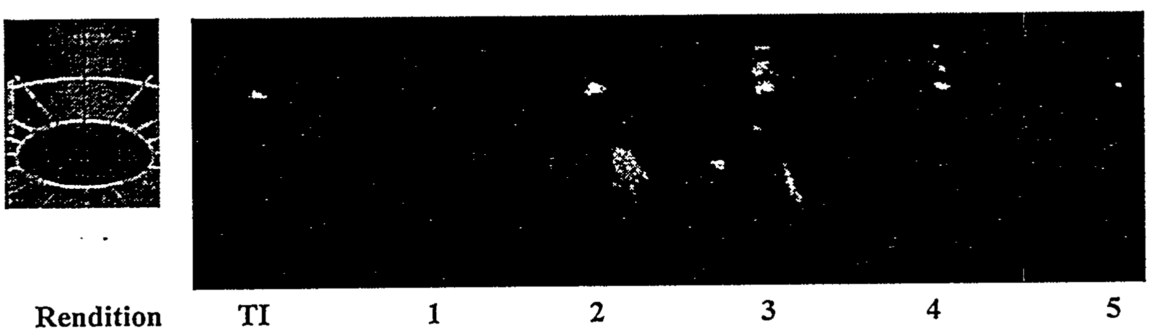

Fig. 7. Scale size rendition of the target compared to a time-integrated frame of the x-ray emission and five 100 ps gated frames 3 ns apart.

Conclusions

Implosion and good coupling to the machine is obtained when arcing and filamentation is reduced. Both prepulse and a conducting coating are necessary for good coupling. The emission moves from the anode to the cathode in all cases. This may be due to the current return configuration and the viewing hole through the mesh. It may also be due to the magnetic field configuration, poorer conductivity at the anode-target interface, or ions crossing the gap at the cathode (generating emission from the cathode surface) late in time.

For these initial experiments we used a configuration that worked with gaspuff z-pinches and identified some limitations. The limitations may be overcome by redesign of the critical electrode contacts and the anode/current return configuration. Future experiments at the PBFA-Z machine will allow us to test these results and provide high power x-ray sources for z-pinch physics and inertial confinement fusion research.

Acknowledgments

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