

# DARHT2 X-RAY CONVERTER TARGET SYSTEM COMPARISON<sup>†\*</sup>

Yu-Juan Chen<sup>†</sup>, Paul M. Bergstrom, Jr., George J. Caporaso, Darwin D.-M. Ho, James F. McCarrick, Philip A. Pincosy, and Peter W. Rambo, LLNL, Livermore, CA

## Abstract

Four short current pulses with various pulse widths and spacing will be delivered to the x-ray converter target on the second-axis of the Dual-Axis Radiographic Hydrodynamic Test (DARHT-II) facility.[1] To ensure that the DARHT-II multi-pulse target will provide enough target material for x-ray production for all four pulses, the target needs either to survive the strike of four electron pulses or to accommodate target replenishment. A distributed target may survive hitting of four electron pulses. For target replenishment, two types of target configurations are being considered: stationary target systems with beam repositioning and dynamic moving target systems. We will compare these three target systems and their radiographic performance.

## 1 INTRODUCTION

Four 20 MeV, 2-4 kA current pulses with various pulse lengths and separations will be focused to sub-millimeter spots on DARHT-II x-ray converter targets. Maintaining a tight spot (*a*) and producing the required x-ray dose present the principal challenges for target design. To produce the required dose, each beam pulse needs to pass through enough target material. Three target concepts are considered. The first one is to reposition each pulse on a static target so that there is fresh target material for each pulse. The radiographic axis is not preserved, and its performance is affected. The second one is to move the target so that the subsequent pulse will strike a fresh target. The third is to distribute the static target material over a larger volume so that the energy density deposited by the beam decreases and target plasma expansion slows down. Thus, there may be enough target material around for the subsequent pulses.

Several effects may impact the spot size on the target. The target plasma created by preceding pulses may expand into the incoming beam's path. The charge neutralization effects produced by target plasma could change the final focus. Thus, the DARHT-II target system needs to provide means to control target plasma expansion. Furthermore, there may be a backstreaming ion problem [2] when the strong electric field created by the electron beam pulls ions in from an adjacent target plasma plume and the target surface. These ions could form an ion channel and change the final focus of the beam. Thus, the DARHT-II target system must also provide for mitigation of the backstreaming ion problem.

In Sections 2 and 3, we will discuss the backstreaming ion problem, target plasma and their mitigation. We will compare the beam repositioning, static target configuration and the dynamic, single axis, target configuration in Section 4. In Section 5, we will present a distributed target configuration for the 2 kA beam,

DARHT-II radiographic requirements. A summary will be given in Section 6.

## 2 BACKSTREAMING IONS AND MITIGATION

A high current beam, impinging on the x-ray converter target with a sub-millimeter spot size, will heat the target and ionize the target material and/or the surface contaminants. Ions can be extracted by the axial space charge field (~a few MV/cm) on the target, and charge neutralize the electron current. The electron beam is then prematurely focused in front of the target and subsequently overfocused at the target. Depending on the charge neutralization factor ( $f_i$ ) and  $q/m$  of the ions, the spot size grows in time, as the ions move upstream, from a few tenths of a millimeter to several centimeters within ~40-60 ns. Regardless of whether there is enough ionization to cause the backstreaming ion problem during a single pulse, the backstreaming ion effect is a concern for a multiple pulse system since by the preceding pulses would have already ionized the target material.

The mitigation being considered for the DARHT-II target is to trap ions within a distance shorter than the 2-3 cm of disruption length,  $L_D \approx a(\pi\gamma\beta^2 I_o/f_i I)^{1/2}$  where  $I$  and  $I_o$  are the beam current and Alfvén current, either by a voltage barrier: an inductive ion trap [3] (Fig. 1) or a resistive ion trap [4], or by a physical barrier: a foil.[5] Simulations indicate that using a voltage barrier can control the DARHT-II beam spot size (Fig. 2a) and maintain the collimated x-ray dose effectively over the entire beam pulse (Fig. 2b). We have chosen the inductive ion trap as the DARHT-II baseline and the foil barrier as the backup plan for ion mitigation.

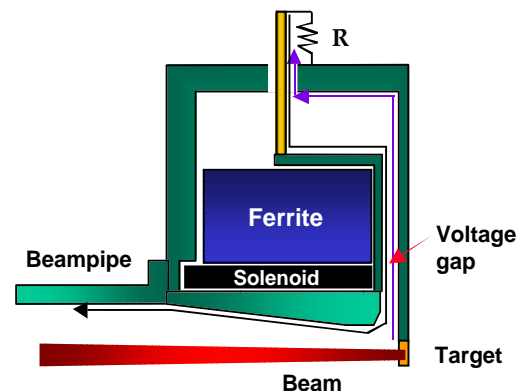


Fig.1 An inductive ion trap self-biases the target by the beam loading effect

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† chen6@llnl.gov

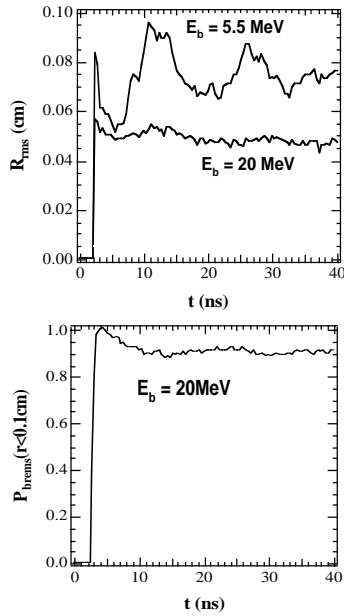


Fig. 2 (a) The R.M.S. spot size and (b) the normalized collimated x-ray dose as a function of time. The ion trap voltage is 370 kV, and the ion trap gap is 2 cm.

### 3 TARGET PLASMA AND MITIGATION

Hydrodynamic simulations [6] of a 2-4 kA, 20 MeV, 0.5 mm radius, 60 ns electron beam striking a 1-mm Ta target show that the target material is generally fully ionized immediately and that the target plasma expands at 1-2 cm/ $\mu$ s axially and  $\sim 1$  cm/ $\mu$ s radially. The plasma electrons' number density varies from  $10^{23}$  cm $^{-3}$  near the target surface to  $10^{12}$  cm $^{-3}$  at the plasma edge which drops to zero within 1-2 mm. The plasma temperature is a few eV at the onset of the subsequent pulse. The magnetic diffusion time is much shorter than the electron pulse length. Thus, the plasma could only neutralize the space charges of the beam but not the beam current. Finally, the target plasma channel in the DARHT-II target region is too short to support growth of the ion hose instability.

The plasma channel's disruption length is about 2-3 cm. The plasma channel may be too long for the fourth pulse at the end of 2  $\mu$ s to maintain a small spot size if the plasma expansion velocity is large. Slowing target plasma expansion and reducing plasma production can minimize the beam-plasma interaction. Distributing the target material over a large volume decreases the energy deposition per unit volume, and hence reduces the initial plasma expansion velocity.[7] The scattered electrons in a distributed target may form a larger cone and deposit energy into more atoms. A smaller energy deposition per unit mass leads to a slower asymptotic plasma expansion. A lower energy deposition per unit mass at the downstream of the target may prevent the downstream target from turning into a plasma. Hence, less plasma is created. Moving the target transversely to the beam axis while the electron beam strikes the target also makes electrons deposit energy in a larger area and in more target atoms. Therefore, using a dynamic target also yields less plasma and slower plasma expansion.

## 4 REPOSITIONING TARGET AND DYNAMIC TARGET

The initial DARHT-II radiographic specifications require delivering four 4 kA, 20 MeV, 60 ns long pulses on the converter with the beam axis to be within 5 mm radius of the radiographic axis. To provide target replenishment, we have investigated two target configurations: a repositioning target and a dynamic (single axis) target. Both target configurations consist of a distributed target and an inductive ion trap. The repositioning target configuration's beamline is different from the single axis beamline [8] only in the few meters before the final focusing lens.

### 4.1 Repositioning Target Configuration

A 4-way kicker system (with a 4-way septum) or a fast deflector system is needed before the final focusing lens. Transport through these systems is difficult. The electron beam's nominal incident angle on the target is 1.36° which would reduce the forward x-ray by 10 % compared with

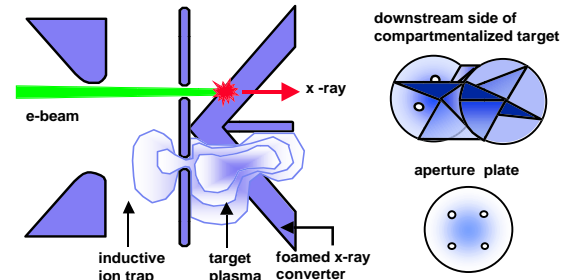


Fig.3 A repositioning target configuration

the x-ray production by a beam with zero incident angle. A compartmentalized, repositioning target configuration (Fig. 3) was proposed by Prono [9] to minimize the beam-plasma interaction. To accommodate four repositioned beams, the upstream aperture of the ion trap is large. This results in a larger required gap voltage and a longer ion trap channel length. Hydrodynamic simulations show that the electron pulses near the end of the 2  $\mu$ s would travel through up to 2.5 cm ( $\sim$  plasma disruption length) of plasma (Fig. 4) [6].

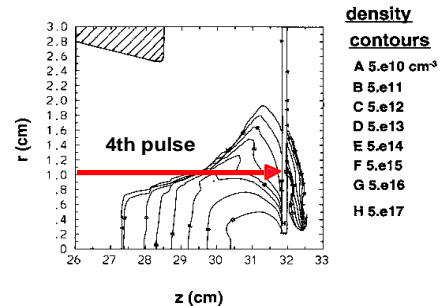


Fig. 4 Static Ta target's plasma density contours at 2  $\mu$ s. The target plasma is created by a 4 kA DARHT-II pulse at the beginning of 2  $\mu$ s.

### 4.2 Dynamic Target Configuration

The obvious advantages of using a single axis, dynamic target are preservation of the radiographic axis and ease

of beam transport without any beam repositioning optical elements. There are also other benefits. For a 0.6 mm radius beam striking a dynamic target moving at 1 cm/ $\mu$ s, reduction in energy deposition per unit mass over a 60 ns pulse would be 25 %, and reduction in the asymptotic plasma expansion velocity is 13 %. Also, a dynamic target moves the target plasma inertially away from the beam axis. Simulations show that none of four 4-kA current pulses will travel through the target plasma if the target is moving faster than 8 mm/ $\mu$ s (Fig. 5) [6]. Three options, a gas gun, shaped charge and flywheel, are available for the dynamic target. They all have difficulties to interface with a target chamber. Dynamic targets tend to be not very clean. However, cleanliness of the dynamic target should not be a concern for a multiple pulse system since an ion trap will be used to confine any target ions and contaminant ions.

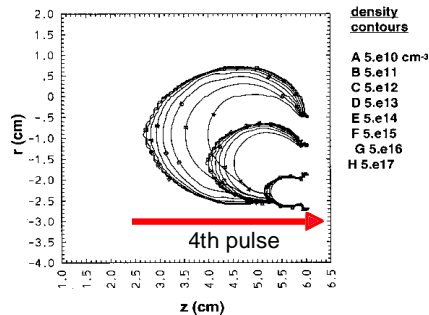


Fig. 5 Target plasma density contours at 2  $\mu$ s for a Ta target moving at 1 cm/ $\mu$ s. Three plasma plumes created by the first three 4 kA DARHT-II pulses separated by 630 ns are shown.

## 5 DISTRIBUTED TARGET

The DARHT-II radiographic specifications for the 2 kA, 20MV beam require the last beam pulse to generate an x-ray dose at 650 R @ 1m and the first three beam currents to generate three much lower dose x-ray pulses. The initial 4-pulse target consists of an ion trap and a static, distributed target that has  $\sim$  20 thin 0.05 mm tungsten sheets distributed over 1 cm and separated by vacuum gaps. The sheets are held within a tungsten cylinder that provides radial confinement of the target. The single pulse, 2-3 kA, 16 MeV FXR experiment using a similar distributed target [7] demonstrated that the downstream side of target foils remained intact, and that the measured x-ray dose and spot size for the distributed foil target was the same as for a solid target as predicted by simulations. We have modeled the distributed target with the 2 kA DARHT-II current pulse format. For each pulse, the calculations include three types of modeling. First, a Monte Carlo calculation, using a given beam spot size, emittance and envelope slope, was done to calculate the beam scattering in the target and x-ray production. A hydro calculation was then carried out to characterize the target plasma. Finally, beam transport through the expanding plasma, including scattering and neutralization of target plasma and energy deposition by electrons, was modeled to determine the next pulse's spot size, emittance and envelope angle. These procedures were repeated

again for the subsequent pulse. To save computation time, the distributed foil target was modeled as a low density, foamed target. The calculations indicate that the configuration of distributed Ta foils within a Ta cylinder can radially confine the target material (Fig. 6). All four electron pulses will travel through the target with a line density equivalent to the line density of a Ta foil thicker than 0.25 mm. Therefore, it permits all four pulses using the same target material to produce the similar x-ray dose for photons within 2-6 MeV energy range.

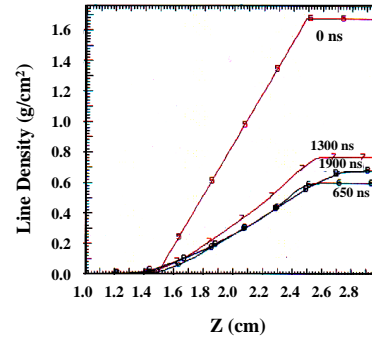


Fig. 6 Target line density for foamed target.

## 6 SUMMARY

We are developing the multiple pulse target system for the second axis of DARHT. Several configurations have been investigated. The baseline for the initial DARHT-II target configuration will consist of an ion trap and a distributed, static target that has  $\sim$  20 thin 0.05 mm tungsten sheets distributed over 1 cm inside a tungsten cylinder and separated by vacuum gaps. The calculations indicate that no target replenishment is needed. However, the target density is the least for the most demanding dose requirement (the 4<sup>th</sup> pulse). We need experimental verification of target survivability through four pulses. Whether the quality of x-ray produced by all four pulses satisfy the radiographic also needs further investigation.

## 7 ACKNOWLEDGEMENTS

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