# EXPERIMENTAL INVESTIGATION OF BEAM OPTICS ISSUES AT THE BREMSSTRAHLUNG CONVERTERS FOR RADIOGRAPHIC APPLICATIONS*

S.Sampayan, G. Caporaso, Y-J Chen, C. Crist†, M. Garcia, T. Houck,
M. Krogh††, R. Richardson, J. Weir, and G. Westenskow
Lawrence Livermore National Laboratory, Livermore, California 94550 USA

*Abstract*

As part of the Dual Axis Radiographic Hydrodynamic Test Facility II (DARHT II) and Advanced Hydrotest Facility (AHF) programs, we have began investigation of the possible adverse effects of (1) backstreaming ion emission from the Bremsstrahlung converter target and (2) the interaction of the resultant plasma with the electron beam during subsequent pulses. These effects would primarily manifest themselves in the static focusing system as a rapidly varying x-ray spot. To study these effects, we are conducting beam-target interaction experiments on the ETA-II accelerator (a 6.0 MeV, 2.5 kA, 70 ns FWHM pulsed, electron accelerator). From these experiments and the multiple diagnostics we have implemented, we are able to determine spot dynamics and characterize the resultant plasma for various configurations. Our data to date shows the first effect to be minimal. We report on the details of our experiments and our preliminary experiments to study the second effect.

## 1 INTRODUCTION

We are presently working on Linear Induction Accelerator (LIA) based radiography projects under the US Department of Energy (DOE). These projects, known as the Dual Axis Radiographic Hydrodynamic Test Facility II (DARHT II) and the Advanced Hydrotest Facility (AHF), are an element of the DOE's strategy of science based stockpile stewardship (SBSS). This program focuses on assuring the safety and reliability of the nuclear weapon stockpile without underground testing. The DARHT II is presently being built at Los Alamos National Laboratory and it is planned that AHF will be built at the Nevada Test Site. Both are national facilities optimized to address weapons issues with minimal environmental impact. The DARHT II machine is a multi-pulse, single-axis flash radiography machine. The AHF machine is a multi-pulse, multi-axis flash radiography machine designed for full 3D imaging. These machines are being designed to be capable of taking a sequence of closely spaced radiographic images so as to produce a time sequenced image of the test object.

On AHF, the process of producing these radiographic images consists of generating a 10-15 shot burst of electron beam pulses at a 1 MHz repetition rate. Each electron beam pulse is approximately 20 MeV energy, 6 kA current, and 200 ns long. These pulses are further chopped into a series of 50 ns sub-pulses and are redirected through a series of magnets to converter targets at each axis. The 20 MeV electron beam impacting the converter target generates an intense x-ray cone which produces a radiographic image on a fast detector array.

The converter target consists of an 0.5-1 mm thick tantalum or tungsten foil. The electron beam is focused to <1 mm and allowed to impinge on this target to create the x-ray pulse. Two effects are of concern. As the electron beam interacts with the target surface, a plasma quickly develops. As the beam electrons creates a strong space charge field in front of the target, ions can be extracted and accelerated in a direction opposite to the electron beam prorogation. These ions partially neutralize the beam space charge and defocusing of the beam results.

The second effect results from the direct interaction of electron beam with the target plasma on subsequent electron pulses. Such an interaction, depending on the interaction length and plasma density, may have an adverse effect on the beam propagation and the resultant spot on the converter target.

Our on-going experimental program at LLNL is to study the interaction of the electron beam with the x-ray converter target. In these experiments, we focus on the dynamics of the spot behavior using optical transition radiation (OTR), measuring x-ray spot blur across an edge (so called "roll-bar" technique), and a gated, multiframe, imaging pinhole camera. Further, we are characterizing the properties of the plume by using Faraday cups, interferometers, and a gated spectrometer. We report on our progress thus far.

## 2 EXPERIMENTAL

The overall layout of the experiment is shown in Fig. 1. Imaging instruments consist of gated, image intensified cameras for observation of Optical Transition Radiation (OTR) from the target surface. Ion diagnostics consist of multiple Faraday cups to observe plasma velocities and to obtain estimates of the plasma density. In addition, to resolve the spatial extent of the plasma as a function of time, an interferometer cavity imaged onto a fast gated or streak camera was implemented. An 0.5 m gated spectrometer allows observation of target optical emissions for species identification and inference of plasma temperature.

As the principal objective of our experiment is to observe the dynamic behavior of the x-ray spot, we have implemented one method of direct observation of the beam spot and two methods to observe the x-ray spot. The first method of observation of the x-ray spot is with a so called “roll-bar” technique. This technique infers spot size from the blur across a hard edge. The second method is by the use of a time resolved x-ray pinhole camera. This latter device consists of tungsten pin-holes imaged onto an x-ray photocathode and amplified with a gated micro-channel plate (Fig. 2). The camera we are using creates 6 sequentially gated images so as to produce a 6 frame movie of the hard x-rays produced from the target interaction during the 70 ns (FWHM) beam pulse. Calculations show optimum sensitivity of the camera to be from 1-2 MeV with a 20% decrease at 5 MeV.

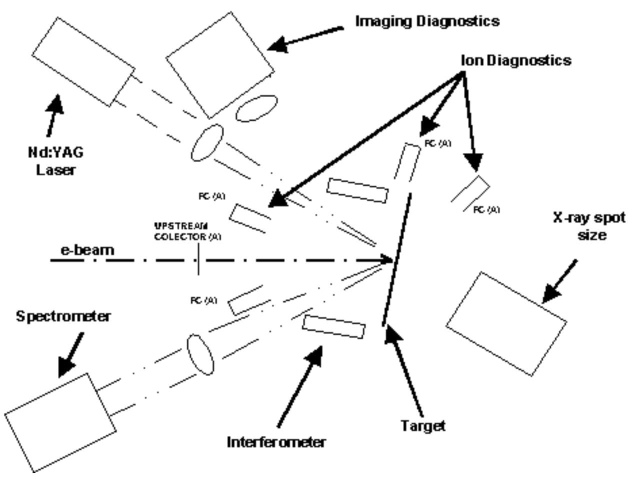


Figure 1. Target experiment layout

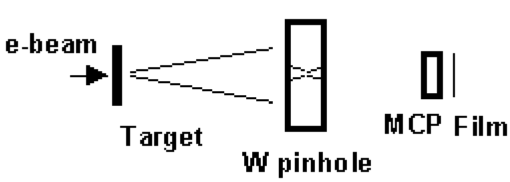


Figure 2. X-ray pinhole camera.

To simulate the effect of a high repetition rate multipulse, we have implemented an 0.8 J Nd:YAG laser focused on the target. The laser beam can be positioned and timed so as to produce a plasma of sufficient density so as to simulate target debris as would encountered in a mutipulse electron beam system.

## 3 RESULTS AND DISCUSSION

Results from the Faraday cup measurements indicate a plasma velocity dependence on spot size, beam parameters, and target thickness [1]. No evidence was found for fast, backstreaming, light ions. The plasma plume was found to expand at 3-4 mm/μs (peak density) with a leading edge velocity of 7-8 mm/μs in agreement with theoretical models.

Target emissions as measured with the spectrometer showed evolution of a prompt line spectra evolving to a black-body like spectra with a peak at about 600 nm when integrated over 8 μs after beam time.

Observations of OTR did not show strong promise as a radius diagnostic when used in conjunction with converter materials of interest (Ta and W). Calculations show that energy deposited into the target at these fluences elevates the material temperature in excess of 1 eV within 4 ns. As a result, prompt thermal radiation with a decay exceeding 1 ms results and observation of a time varying spot becomes difficult. The radiation is so intense and spectrum sufficiently broad that even with the inclusion of high quality short wavelength pass filters in the optical chain, extraction of the OTR signal was not possible.

Roll bar measurements were also performed. As scatter and depth of field issues can reduce the system resolution, a significant effort was necessary to optimize the trade-off between scintillator thickness (used in conjunction with a gated or streak camera for imaging) and pixel noise. Never-the-less, system resolution was limited from 0.75-1.5 mm. Correlation was also attempted with the OTR images under identical accelerator tuning conditions. Generally, we observed reasonable correlation (order 50%) between these measurement techniques. Additional reporting of this data is contained in a separate paper [2].

Figure 3 shows a representative sample of image data from the x-ray pinhole camera [3]. In this particular data, the orientation of the target was changed from 15$^{o}$ off normal (top) to normal incidence (bottom).

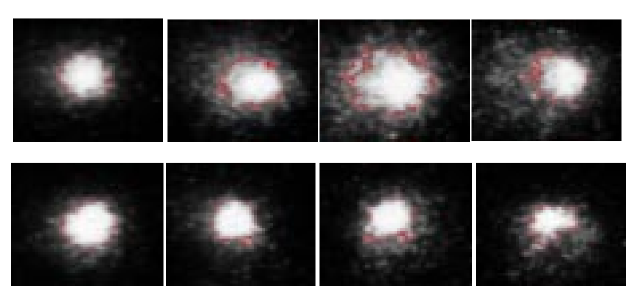

Figure 3. Time resolved x-ray spot comparison between 15$^{o}$ off normal (top) and normal incidence (bottom).

The top images were taken with the target at 15$^{o}$ off normal show expansion and filamentation of the beam. Gate time of each image is approximately 6 ns and spacing between images is 7-10 ns.

This effect can be explained by the asymmetric foil focusing forces which occur at the target as result of the angled target. The lower images, taken with the beam at normal incidence with all other remaining conditions identical, show an almost constant spot diameter. An intensity profile through the center of other similar images taken at a 1 mm spot diameter (FWHM) and 1.4 kA are shown in Figure 4. Again, these data show an almost constant spot radius with a variation of approximately 25%. Shown with these data, is the expected expansion of the spot resulting from backstreaming $H^+$ ions. From this comparison, we have concluded that backstreaming ion defocusing is not a strong effect with these beam parameters.

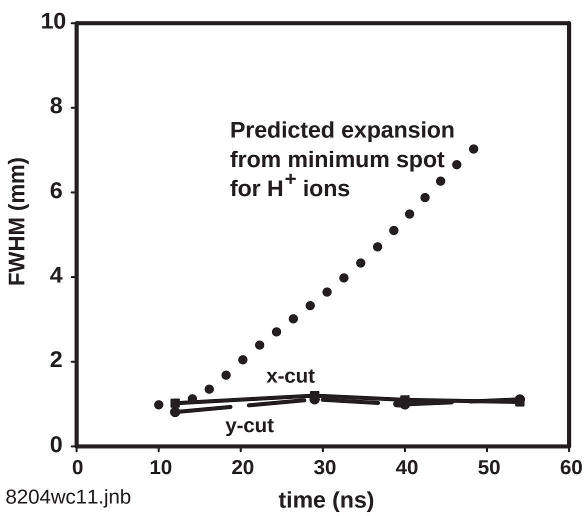


Figure 4. Time resolved images of x-ray spot (6 ns gate time, 10 ns intervals).

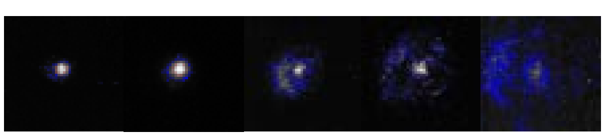

Figure 5. Spot expansion resulting from a laser induced plasma.

Initial data from the interaction of the electron beam with a laser induced plasma is shown in Figure 5. The beam maintains a 1 mm (FWHM) core and the 2σ threshold expands from 1.5 mm to 12 mm (last frame). With this particular data set, the laser was fired at approximately 100 ns before beam time and co-located with the electron beam position on target. Faraday cups indicate an expansion velocity of approximately 5 cm/µs and density at the Faraday cup (spaced 24 cm from the target) of $2 \times 10^{10}$ $cm^{-3}$. Combing these data indicates an interaction length of 0.5 cm and an inferred density within that region of $5 \times 10^{18}$ $cm^{-3}$. Initial analysis of the data shows this behavior is dominated by a backstreaming ion affect.

To minimize the interaction of the plasma with the beam, we are considering dynamic targets in our baseline development program. Such a technique will provide fresh target material pulse-to-pulse and also add a transverse component to the plasma so as to inhibit a direct beam-plasma interaction.

The dynamic target delivery scheme required study of several relatively mature technologies: high velocity fly wheels, shape charge jets, and both the burning propellant and compressed gas driven versions of high performance guns, i.e., light gas guns..

The fly wheel offers a significant advantage over all of the other methods because it does not need to be synchronized with other hardware in the system or the test object. Velocities are limited to 5 mm/µs, however. Shape charged jets offer the advantage of a very short cycle time for the total operation of injection of the target material. They also can reach the required velocities but work is required to create the necessary target crossection. Gas guns have the capability for deliver of materials with the velocity required to meet the replenishment need of the radiography systems. Velocities of 8 mm/µs, consistent with the target requirements, are not uncommon from these guns and some research guns are proposing speeds of nearly a factor of 2 faster Calculations have been performed with a basic two-stage system and indicate that a total system jitter for the gun will be 1.5 µs for a gun operated in the 5 mm/µs range.

## 4 SUMMARY

We have described our ongoing experiments to determine the effects for a multipulse Bremsstrahlung converter target used for radiography. An ion backstreaming and plasma interaction effect have been defined as the two of the most predominant mechanisms which could degrade the focal spot on the target. The first effect was studied, no obvious effects were found. Study of the second effect was initiated and appeared to be dominated by an ion effect. Alternative target systems are being studied to minimize this second effect.

## 5 REFERENCES


[1] T. Houck, et.al., “Faraday Cup Measurements of the Plasma Plume Produced at an X-ray Converter”, these proceedings.

[2] R. A. Richardson, et.al., “Roll Bar X-ray Pot Measurement Technique”, these proceedings.

[3] C. E. Crist, et.al., “Time Resolved, 2-D X-ray Imaging of Relativistic Electron-Beam Interactions on ETA-II”, these proceedings.



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† Sandia National Laboratory

†† Allied Signal