DOE/NV/11718--783

DEVELOPMENT OF A DYNAMIC SPOT SIZE DIAGNOSTIC FOR FLASH RADIOGRAPHIC X-RAY SOURCES

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Abstract

There has been considerable work in recent years in the development of high-brightness, high-dose flash x-ray radiographic sources. Spot size is one of several parameters that helps characterize source performance and provides a figure of merit to assess the suitability of various sources to specific experimental requirements. Time-integrated spot-size measurements using radiographic film and a high-Z rolled-edge object have been used for several years with great success. The Advanced Radiographic Technologies program thrust to improve diode performance requires extending both modeling and experimental measurements into the transient time domain. A new Time Resolved Spot Detector (TRSD) is under development to provide this information. In this paper we report the initial results of the performance of a 148-element scintillating fiber array that is fiber-optically coupled to a gated streak camera. Spatial and temporal resolution results are discussed and the data obtained from the Sandia National Laboratories (SNL) RITS-3 (Radiographic Integrated Test Stand) accelerator are presented.

I. INTRODUCTION

A common parameter used to characterize radiographic x-ray source performance is the source spot size. This parameter, coupled with dose and end-point energy, provides the radiographer with information about the source suitability for a particular application. One of the most common methods of spot-size measurement uses negative x-ray film viewing the source across a high-Z object and observing the sharpness of the edge. During the development of the RITS flash x-ray source at SNL, the need also developed for time-resolved or dynamic spot-size measurement, capable of providing temporal information about the performance and behavior of the diode. This information then could be used to validate physics based models that are used to design and optimize diode sources.

As a result, a new diagnostic system for flash radiographic x-ray sources has been developed that enables one to make measurements of intense, dynamically-evolving x-ray source spots. The sensor uses a plastic scintillating fiber array, arranged perpendicular to a bremsstrahlung

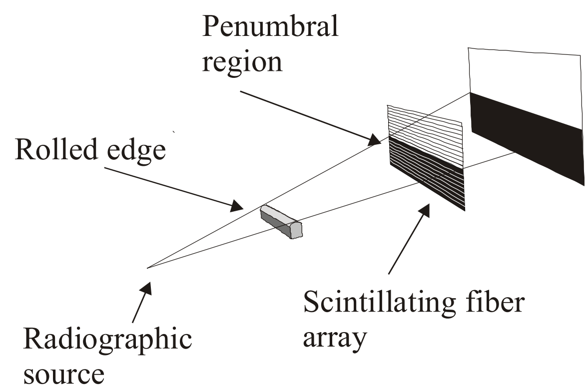

Figure 1. Conceptual sketch of detector array.

beam and parallel to the prenumbral shadow cast by a high-z rolled edge (Figure 1).

Each scintillating fiber is an individual sensor, reporting the dose integrated along the length of the fiber filament. The plastic scintillator array is then coupled, one-to-one, to a linear step index quartz fiber array, which in turn is coupled to a gated streak camera. The streaked image is recorded on film and analyzed using linear regression techniques. Parameters are extracted to describe source spot size, relative dose rate, and source motion in a plane perpendicular to the rolled edge.

II. SENSOR DESCRIPTION

A scintillating fiber array was designed and built that consists of 148 plastic scintillating fibers (Bicron BSF-20), each ~250-µm in diameter by 40-mm in length. The fibers were epoxy potted in a V-groove substrate and were initially held in place with an acrylic cover slip. In the 2 to 10 MeV range, Compton electron production in the scintillator is the predominant energy deposition mechanism. Since Compton electron production has a wide angular spectrum, it is necessary to keep the sensor thin along the beam axis to maximize resolution. Therefore, after the potting of the array was hardened, the acrylic cover slip was milled to a thickness of 100 µm.

Placing a thin mirror on the far side of the array enhanced photon collection. A photograph of the array is shown in Figure 2.

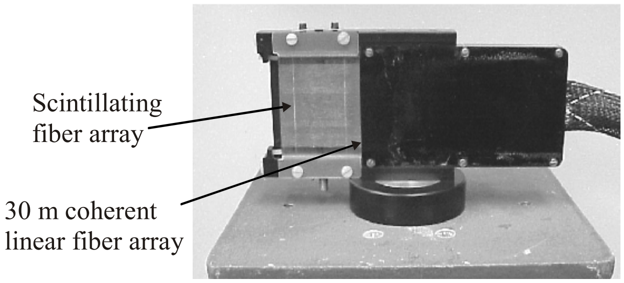

Figure 2. Photograph of scintillating fiber array.

Attached to this cover slip is a 5-mil thick Pb foil. The purpose of the foil is to equalize the x-ray beam and to shield the sensor from very low energy electrons present in the scattered radiation.

As previously described, the scintillating fibers are coupled to a coherent, fiber optic array. The fiber array output is lens coupled to a streak camera through a narrow band optical filter. The optical filter has a 500x50 nm band pass and is centered on the scintillator emission maximum. The optical filter is necessary to reduce broadband Cerenkov radiation, presumably created in the quartz fiber. Without the filter, the edge contrast was reduced to near zero.

Figure 3 shows the configuration for a set of experiments performed on the SNL RITS-3 accelerator [1]. A magnetic self-pinch diode was used to provide a small (<5 mm) spot with interesting dynamic behavior. The RITS pulse power source drives this diode to energies on the order of 4.5 MeV, provides a dose of ~50 R at 1 meter and has a pulse duration of about 60 ns. Due to the limited (4 cm) spatial extent of this sensor, one has to be judicious in the selection of a radiographic magnification. For these tests, the magnification was set to approximately 2.0. Additionally, one has to take care that the scintillating fibers are placed parallel to the rolled edge, as any misalignment here will result in reduced resolution of the detector.

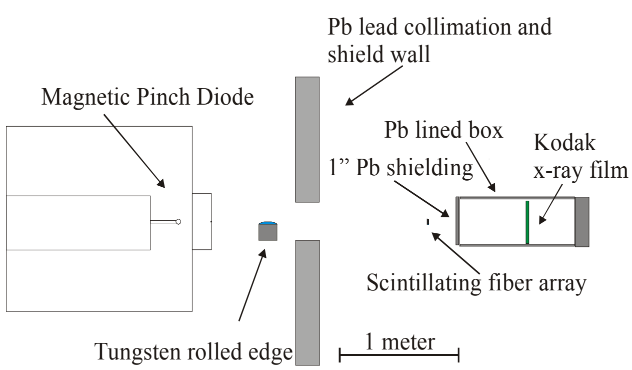

Figure 3. Sketch of experimental configuration.

For these experiments, Kodak x-ray film packs were also fielded. Comparisons were made between the time-integrated response of the Kodak film and the time-integral of the TRSD.

III. RESULTS

The results of three shots are presented in this paper. Shots 239 and 240 were made with an anode-cathode (A-K) gap of 8.75 mm. For shot 241, the A-K gap was reduced to 7.5 mm.

With the fibers arranged parallel to the rolled edge, the 40-mm length of the fibers sum the x-ray dose along the edge, enhancing the measurement signal-to-noise ratio. Since the sensor is very thin (~350-µm) along the axis of beam propagation (z-axis) the degradation of image quality due to radiation scattering within the sensor is minimized. Hard edge measurements, coupled directly to the sensor, show a 3- to 4-fiber-width spatial edge response. The time response of the system is limited by the decay time of the scintillating fibers, quoted by the manufacturer to be 2.7 ns.

Figure 4 shows digitized film data of three streak camera images from RITS shots 239, 240, and 241.

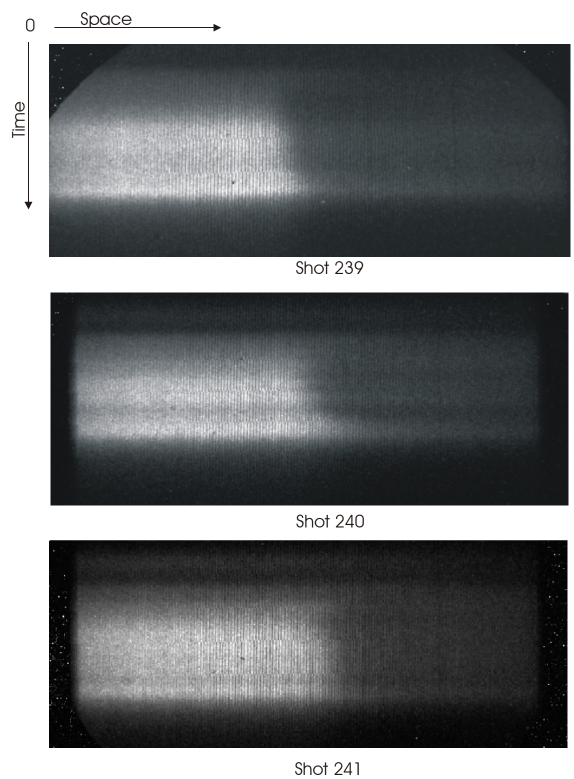

Figure 4. Streak camera images from shots 239, 240 and 241

These images have been corrected for the non-linear response of the streak camera film readout using a measured transfer function. This transfer function was obtained by exposing a film with a sensitometer step wedge and developing it in a typical manner.

Individual fibers are visible in the images and are seen as vertical lines in the center part of the image.

The shadow of the rolled edge target is seen in the middle of the image. Data analysis is begun by reading one horizontal pixel line at a time. These data lines are then fit with a Sigmoid transition function. A typical line of data, taken from shot 241, is shown in Figure 5.

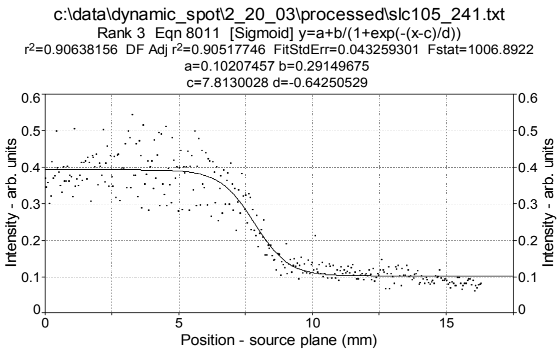

Figure 5. Typical data line from shot 241.

The noise present in the pulse is due to modulation induced by the partially-resolved single fibers. These data have been flat-field corrected, which should, in principle, remove the fiber modulation. However, because these data are recorded on hard film, rather than a CCD camera, registration of the flat field with the data is difficult and not exact. In spite of the noise, the functional fits work well and appear to converge to meaningful results.

Figure 6 shows a graphical summary of the results from these three shots. Plotted on each graph is a measure of the dose rate (pulse shape), spot size, and spot position. Relative dose rate is extracted from parameter "b" in the Sigmoid-based regression. This parameter is a measure of the height of the transition function, which is proportional to the dose rate.

The spot size is based upon the Atomic Weapons Establishment (AWE) definition and is determined using the functional fit [2]. First one subtracts the offset and normalizes the peak, and then the 25% to 75% value is determined. This value is then multiplied by 2.5, and is shown plotted as the thick solid line on the graph.

The dotted lines in Figure 6 show a shift in the position of the beam, as derived by subtracting an offset from parameter "c" (see graph label Figure 5) of the Sigmoid fit, and plotting the result verses time. These shifts can be clearly seen as left-right movement on the edge in the streak camera image data shown in Figure 4.

One can obtain a check of these results by comparing the time integral of the streak camera data with results obtained from conventional x-ray film cassettes. Figure 7 shows such a comparison on shot 241. As seen in this plot, there is good agreement between film and dynamic sensor data. To obtain this agreement however, it was necessary to subtract an offset from and re-normalize the dynamic data. Automated processing reported a spot size of 3.2 mm for the Kodak film and 5.6 mm for the dynamic sensor. This difference appears to be connected

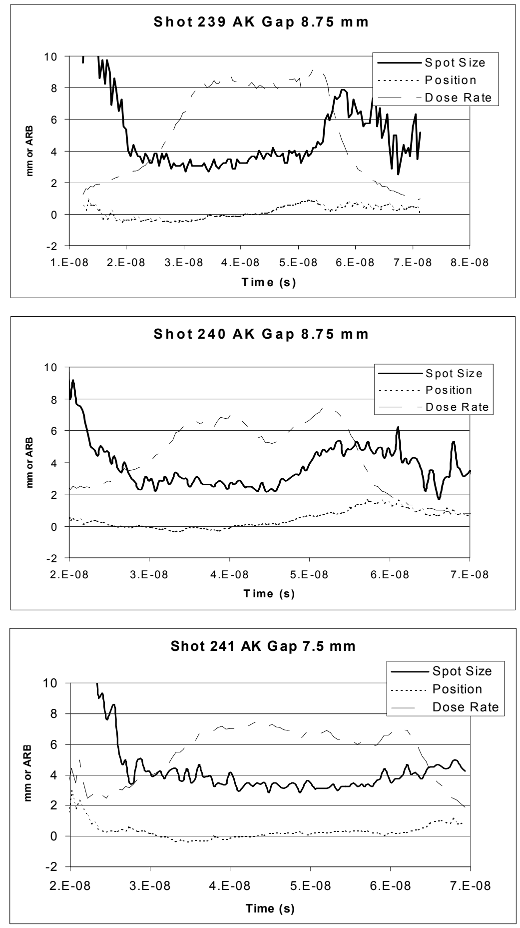

Figure 6. Spot size, position, and dose rate data extracted from TSRD.

to the nature and extent of the long tail, shown in Figure 7, along with automated determination of base lines and 100% points. It should be noted that the collimation and the "hardness" of the x-ray beam were substantially different for the geometries of these two sensors.

Another application of this dynamic detector is that it should, in principle, act as a bridge between the time-integrated spot measurements and the time-resolved PIN. Comparing the spatial integral of the streak camera data with silicon PIN data can make a further check of the response of this sensor. Figure 8 shows an overlay of the normalized PIN data the spatial integration of shot 242. As seen in Figure 8, it was not possible to obtain a perfect match between the scintillating fiber sensor and PIN data. The two sensors had different lines-of-sight, with the scintillating fiber array on axis while the PIN detector viewed the source off-axis at approximately 35 degrees. Differences are seen primarily in the magnitude of the vacuum precursor voltage. Initially this difference was thought to be caused by inaccuracies in the sensor transfer function. However the fact that the PIN data shows less vacuum precursor voltage while exhibiting more tail, implies that the issue is subtler than a simple calibration.

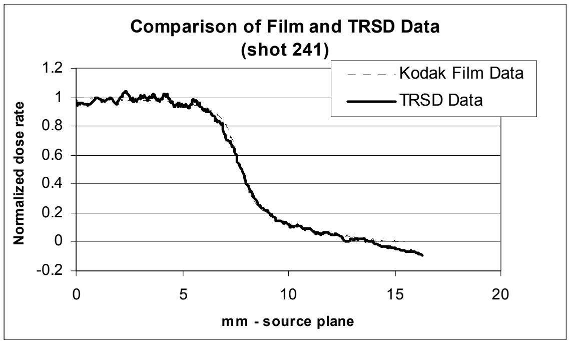

Figure 7. Comparison of Kodak film and TRSD results.

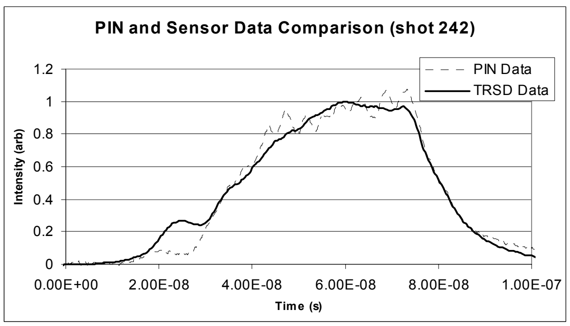

Figure 8. Comparison of TSRD and PIN data.

IV. CONCLUSIONS

We have presented dynamic spot characterization data taken with a fiber optic array sensor, as well as a data-extraction methodology. The sensor is capable of sensing both movement and broadening of a radiographic beam spot. Data comparisons were made with conventional hard film and Si PIN detectors.

V. ACKNOWLEDGEMENT

We would like to thank: Mike Grover (BN/STL) for assembly of the scintillating fiber array; Guy Leach (BN/STL) for the design and construction of the scintillator V-groove block and fiber array coupling; and the RITS accelerator team for their assistance in fielding and efforts in making the machine run.

This work was supported by the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, under Contract No. DE-AC08-96NV11718. **DOE/NV/11718—783**.

VI. REFERENCES

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