ROLL BAR X-RAY SPOT SIZE MEASUREMENT TECHNIQUE*

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Abstract

A time dependent x-ray spot size measurement is critical to understanding beam target physics such as target plasma generated beam instabilities. The so-called roll bar measurement uses a heavy metal material which is optically thick to X-rays, to form a 1D shadow of the x-ray origination spot. This spot is where an energetic electron beam interacts with a high Z target to produce the x-rays. The material (the "roll bar") has a slight radius to avoid alignment problems. If a beam profile is assumed (or measured by other means), the equivalent x-ray spot size can be calculated from the x-ray shadow cast by the roll bar. Typically a radiographic film is exposed over the duration of the beam pulse, and the shadow is analyzed for a time integrated measurement. This paper explores various techniques to convert the x-rays to visible photons which can be imaged using a gated camera or streak camera for time evolved x-ray spot size. Data will be presented from the measurements on the ETA II induction linac.

1 INTRODUCTION

This diagnostic is used to measure the spot size of an x-ray source. A bar that is optically thick to x-rays is used shadow the source, acting as a knife edge. This produces a shadow that is effectively the integral of the x-ray profile. We assume that the profile here is Gaussian in shape. The profiles are fitted to a erfc function, which is the integral of a Gaussian. The Gaussian assumption is verified using other diagnostics such an x-ray pinhole camera and OTR (optical transition radiation) of the focused electron beam striking the surface of an x-ray target.

The shadowed x-rays are then converted to visible photons for imaging using commercial cameras. The image is corrected for flat field using an image taken without the rollbar present. The image is averaged in the dimension orthogonal to the rollbar edge to increase photon statistics.

The full-width half maximum (FWHM) of the Gaussian (from the fitted erfc function), corrected for magnification, is reported as the spot size. The magnification of the rollbar is simply the distance from the rollbar to the x-ray image converter (scintillator) divided by the distance from the x-ray source to the rollbar (Fig. 1).

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Limitations of this diagnostic are the blurring effects due to the finite thickness of the image converter. This can be reduced by increasing the magnification, but at a cost of reduced x-ray flux. The photon conversion efficiency is low, so that detection is marginal for short gate widths and large magnification.

2 EXPERIMENTAL SETUP

This diagnostic is used to measure the x-ray spot on the ETA II linear electron accelerator. The machine parameters are 5.5 MeV energy, 2 kA current, 50 ns pulse width. X-rays are created when the beam is focused on a (typically) 0.040" Tantalum target. The diagnostic setup (Fig. 1) consists of a heavymet (mostly Tungsten) rollbar, which is a 8x8x3 cm block with a 1 meter radius machined on one face. This bar is located a distance 108 cm from the target (x-ray source). Between the target and the rollbar is a 0.060" aluminum vacuum window. At a distance of 427 cm there is a 90x90x19 mm BC-400 scintillator. The magnification is therefore 3.95. We use a 0.010" tantalum sheet in front of the scintillator to convert the x-rays to electrons which are detectable by the scintillator. Black cloth between the tantalum and scintillator absorbs reflections.

The scintillator is imaged using a gated camera. We have used a Cohu SIT camera (10 ns gate) and a Princeton Instruments CCD camera (5 ns gate). Both cameras use a microchannel plate to intensify and gate the image.

Typically a short lead bar is placed directly in front of the scintillator-Tantalum stack orthogonal to the direction of the rollbar edge, partially blocking the x-rays. This is done to provide an edge that is representative of the blurring introduced by the scintillator and camera. The optical resolution is typically much less than the scintillator blur.

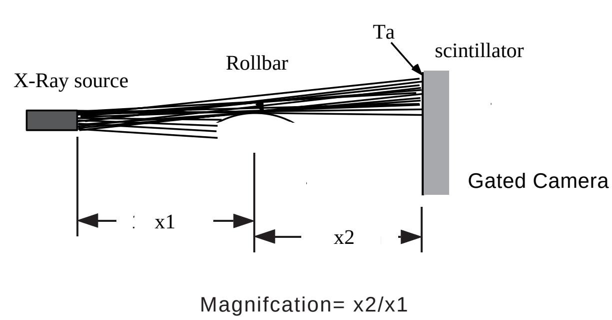

Figure 1: Sketch of rollbar diagnostic.

3 DATA

An example rollbar image is shown in Fig. 2. This is the raw scintillator image, uncorrected for flat field. The scintillator is imaged with the Princeton Instruments camera (ICCD-576). The 5 ns gate of the camera is timed to the middle of the accelerator pulse. The dark frame around the scintillator is clearly visible. The rollbar in this case is vertical, and an averaged lineout in the horizontal direction is analyzed to get the spot size of the x-ray source. The sharper horizontal shadow in the lower half of the image is due to a 0.25 inch thick lead bar placed immediately in front of the scintillator. Lineouts in the vertical direction are analyzed to approximate the blurring due to x-ray and electron scattering in the scintillator and tantalum backing, as well as optical blurring.

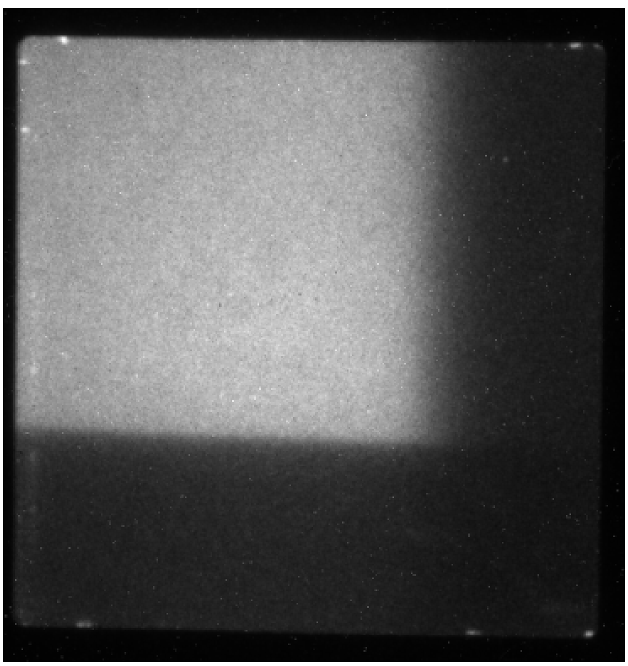

Figure 2: Scintillator image showing rollbar and edge blur x-ray shadows.

A horizontal lineout and erfc fit are shown in Fig. 3. This is the raw data, uncorrected for any blur. A lineout of the image in the vertical direction, which shows the shadow from the lead bar is shown in Fig. 4. An erfc fit is done on the data to quantify the blur produced. As expected, the fit is not perfect, but gives a representation of the spot size error, in this case around 1 mm.

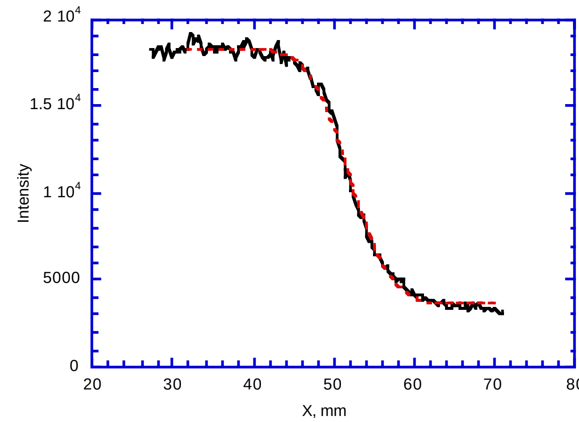

Figure 3: Rollbar data with erfc fit. Magnification=4, Gaussian FWHM = 2.4 mm.

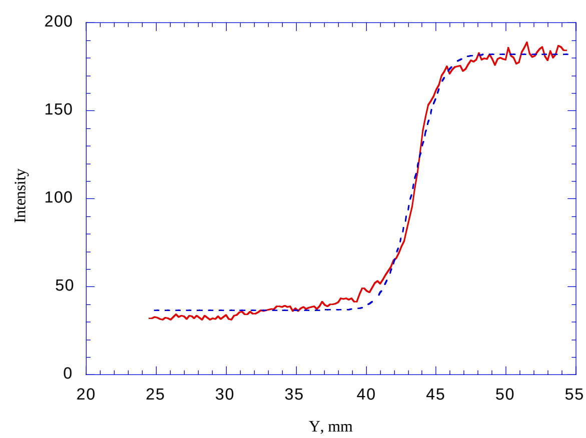

Figure 4: Scintillator blur with erfc fit. The equivalent spot size is 0.97 mm.

The scintillator blur can be corrected for by deconvolution of the data with the blur[1]. This is done using Fourier transforms of the data. First the data is smoothed and differentiated. The Fourier transform of the data is taken and normalized to give the modulation transfer function (MTF). The spot size can be obtained by finding the frequency (f_0) at which the MTF = 0.5. The equivalent Gaussian spot size is then FWHM = $0.447/f_0$. The resulting transforms are shown in Fig. 5. The spot size of 2.5 mm when corrected for scintillator blur drops to 1.9 mm. This method of spot size determination is more effected by noise. Note there is a slight difference in the uncorrected spot size when determined by FFT or erf fit to the raw data (2.5 versus 2.4 mm).

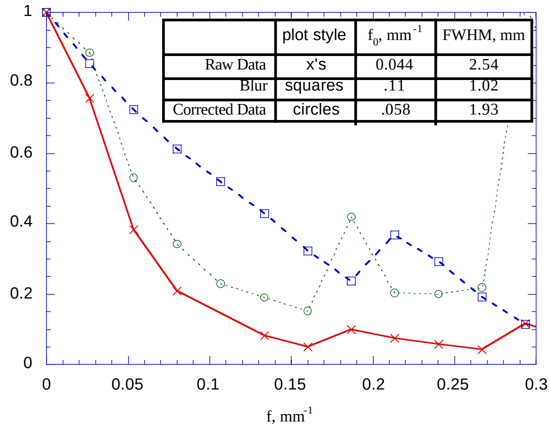

Figure 5: Fourier transforms of image lineouts, with corrected data.

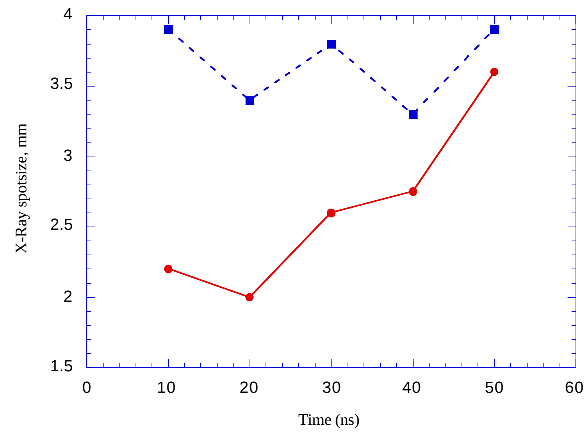

Figure 7: X-ray spot size versus time for two different magnet settings (solid and dashed curves).

4 RESULTS

The rollbar diagnostic is useful for final tuning of the accelerator. The image data is recorded real time electronically. The lineouts and fit can be done in a manner of minutes, and a tuning curve can be generated rapidly, Fig. 6.

The rollbar diagnostic can also be used to determine the time history of the x-ray spot, Fig. 7. For this data, each point represents a different shot, so some shot-to-shot stability must be assumed.

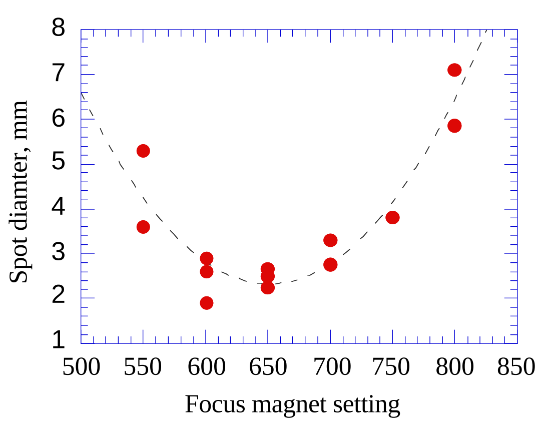

Figure 6: X-ray spot size tuning curve.

5 ACKNOWLEDGMENTS

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6 REFERENCES

[1] N. Back., internal LLNL memo