

OPTICAL DIAGNOSTICS ON ETA II FOR X-RAY SPOT SIZE*

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Abstract

Gated and streak cameras have been used to look at a high current focused electron beam on a target, and the x-rays produced by that interaction. An optical camera images the optical transition radiation (OTR) from the beam hitting a carbon target to give focused beam profiles. Blackbody radiation from heavy metal targets is experimentally proven to be dominant. The roll bar technique is used as a thick knife edge to 'image' the x-ray spot produced by the beam-target interaction. The x-ray shadow is converted to visible photons using a scintillator and imaged using a gated optical camera. The scintillator thickness places a limit on the resolution of the diagnostic. Data will be presented from these techniques and compared to an x-ray pinhole camera.

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 to 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 an erfc function, which is the integral of a Gaussian. The Gaussian assumption is verified using other diagnostics such as a x-ray pinhole camera.

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. 3).

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.

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The ultimate limiting resolution of the roll bar is set by the finite radius of the roll bar. While a flat surface would provide an ideal knife edge, a small misalignment of this edge degrades the resolution rapidly. This effect is reduced if the edge is a cylinder, Fig. 1. The resolution is calculated by assuming a photon takes a straight line geometric path from an ideal point source and is attenuated by the roll bar exponentially, $I=I_0 \cdot \exp(-\mu x)$, where x is the amount of high density material that the x-ray photon passes through, and μ is the 5.5 MeV extinction coefficient, taken as 81 m^{-1} for tungsten. This ignores any scattering effects and is only a lower limit calculation for the resolution. For the parameters in this paper, this calculation gives a limiting resolution of 0.09 mm, calculated from the FFT of the intensity plot in Fig. 2.

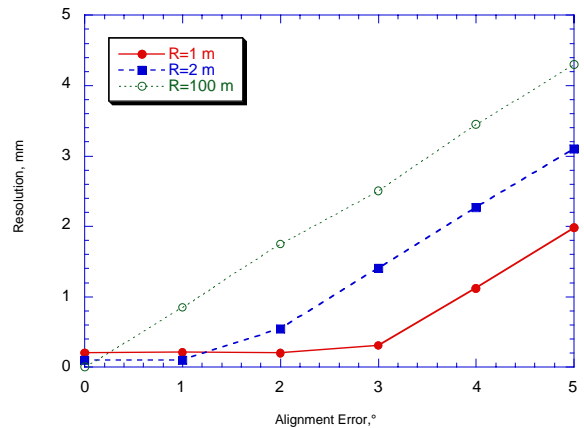


Figure 1: The ultimate resolution of the rollbar versus the alignment angle, the parallelism to the source. R is the rollbar cylinder radius.

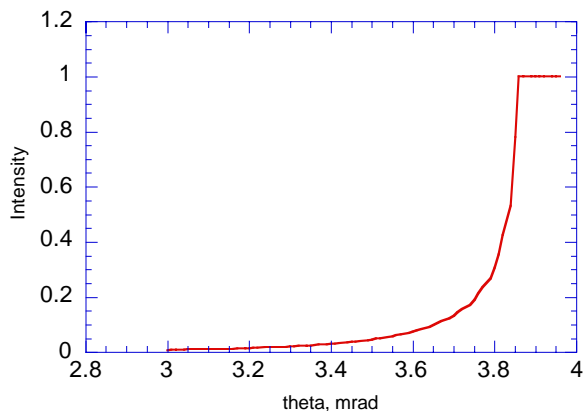


Figure 2: The calculated effect of a rollbar with radius of 1 m and alignment error of 1°. Theta is the angle of a photon from a point source.

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) 0.005" Tantalum target. The diagnostic setup (Fig. 3) 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.

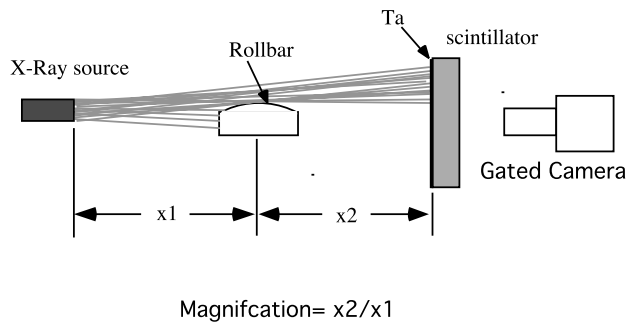


Figure 3: Diagnostic setup.

3 DATA

An example rollbar image is shown in Fig. 4. 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.

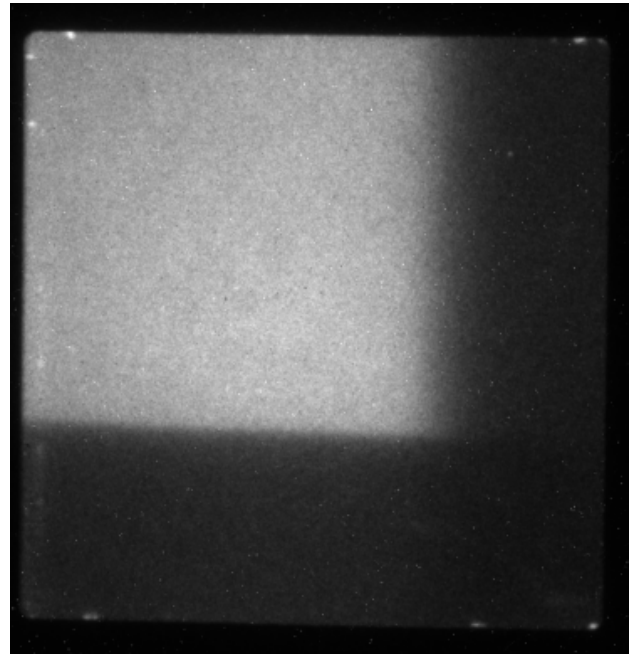


Figure 4: Scintillator image showing rollbar and edge blur x-ray shadows.

A horizontal lineout and erfc fit are shown in Fig. 5. 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. 6. 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.

The scintillator blur can be corrected for by deconvolution of the data with the blur. 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 $FWHM = 0.112/f_0$. The resulting transforms are shown in Fig. 7. The spot size of 2.5 mm when corrected for scintillator blur drops to 1.9 mm. Also plotted in Fig 7. is the FFT of the calculated rollbar resolution limit of Fig. 2.

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 erfc fit to the raw data (2.5 versus 2.4 mm).

4 RESULTS

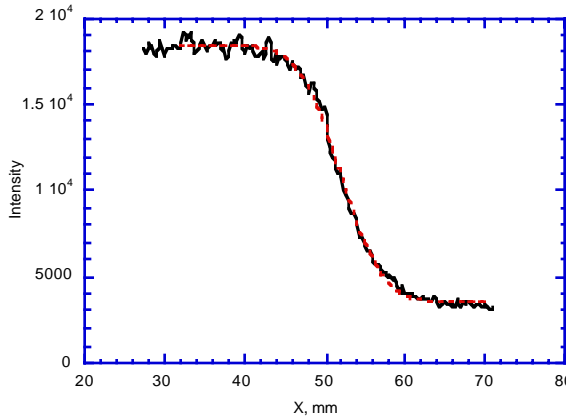


Figure 5: Rollbar data with erfc fit. Magnification=4, Gaussian FWHM = 2.4 mm.

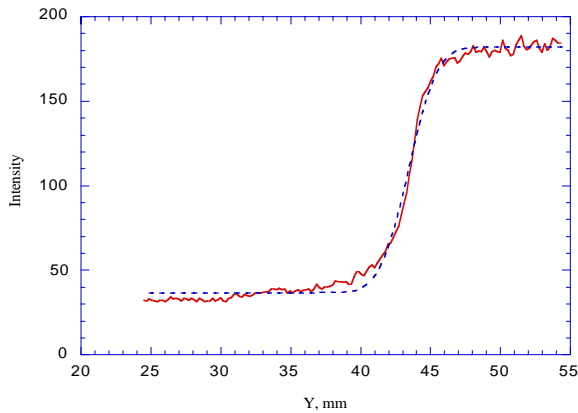


Figure 6: Scintillator blur with erfc fit. The equivalent spot size is 0.97 mm.

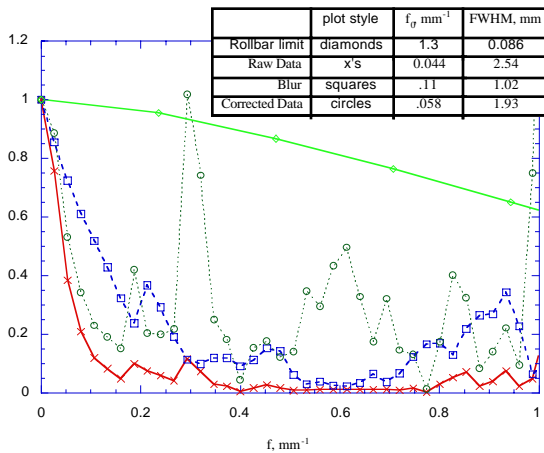


Figure 7: Fourier transforms of image lineouts, with corrected data.

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. 8.

The rollbar diagnostic is compared with data from a x-ray pinhole camera in Fig. 9. The scintillator blur for this data set limited the resolution of the rollbar to about 2 mm.

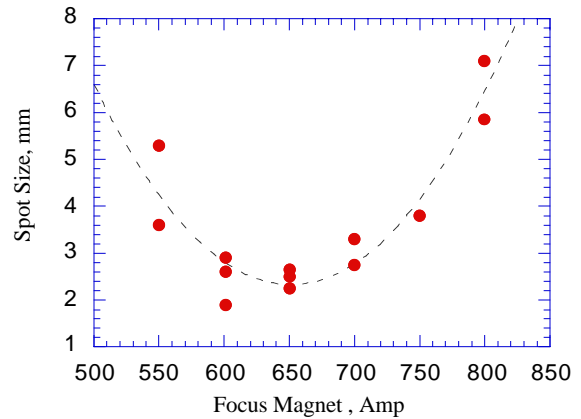


Figure 8: X-ray spot size (FWHM) tuning curve.

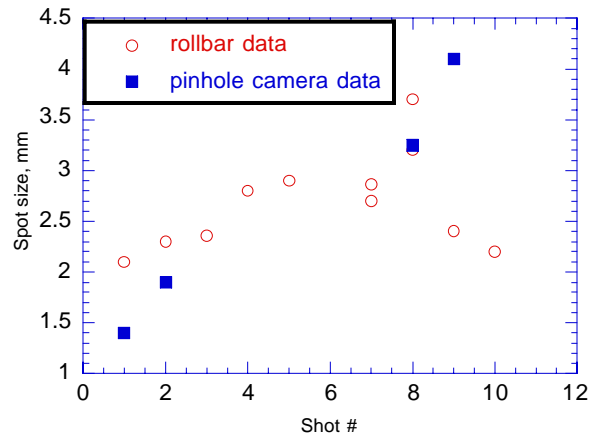


Figure 9: Rollbar calculated spot size and spot size calculated from the x-ray pinhole camera.

5 ACKNOWLEDGMENTS

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