RADIOGRAPHIC PERFORMANCE OF CYGNUS 1 AND THE FEBETRON 705*

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Abstract

Spot sizes are measured for medium energy x-ray generators. The Cygnus x-ray source [1] is developed for support of the Sub-Critical Experiments Program at the Nevada Test Site. Cygnus uses proven pulsed power technology to drive a rod pinch diode at 2.25 megavolts. Four rads at one meter is achieved in a 50-ns FWHM pulse and the radiographic spot size is as small as 1 mm-diameter. Radiographic spot size is measured employing roll bars and resolution targets. Images are recorded on film and storage phosphor, digitized, and analyzed. The Febetron 705 x-ray source operates at 2.3 megavolts and is rated at 500 millirads at one meter. A demountable diode tube provides the ability to replace the standard diode with custom hardware. Spot sizes for standard hardware are measured. New diode designs are investigated in an effort to generate smaller radiographic spot sizes to produce improved radiographic images.

I. IMPORTANCE OF SMALL SPOT SIZE

The control of several parameters are required to produce a radiograph of high quality. Three obvious contributors to quality are: film blur, motion blur and spot size. This paper deals with spot size.

Small spot size contributes to a high quality radiograph by casting a sharp shadow. Another way to express this, in mathematical terms, is that a small spot has high spatial frequency components. Small features in the object will be illuminated by high spatial frequency components of the irradiating beam and obscured by low spatial frequency components.

One way to minimize the problem of large spot size is to bring the recording medium close to the object. Photographic contact prints use this method. However, images are limited to a one-to-one magnification. For x-ray radiography, objects are often three dimensional, so strict contact with the recording medium cannot be maintained. Radiographs of objects in the process of exploding also recommend themselves for techniques that remove the recording medium from intimate contact with the object. Typical recording media include film, storage phosphors and digital cameras.

We have endeavored to produce an x-ray generator capable of producing a nominal 1-mm spot size to meet the requirements of our experiment.

II. CYGNUS I

Two Cygnus x-ray generators are designed for use underground. This requirement has driven the design to produce a narrow generator, with the Marx bank, pulse forming line, inductive voltage adder and diode in line with each other. Two x-ray generators allow images to be obtained from two views at two times. Two generators, placed in line with each other, create a narrow footprint, consistent with underground siting.

The x-ray generating diode is of the rod pinch type [2]. A thin anode rod protrudes through an annular cathode. A positive pulse on the anode produces electrons from the cathode. There is an interaction between electric forces from the diode and magnetic forces from the electron current, complicated by plasma generation on the anode. The rod pinch diode on Cygnus is remarkable for producing a 1-mm scale spot size for 50 ns with relatively constant impedance, approximately 35 ohms.

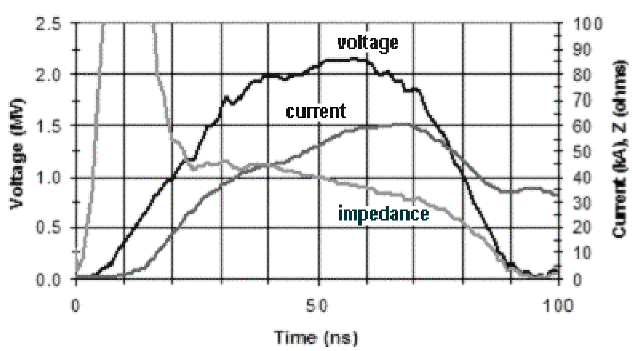

Figure 1. Operation of Cygnus with a rod pinch diode. Voltage waveform peaks at 2.2 MV. Current peaks at 60 kA. Impedance falls during the pulse.

Radiation is monitored using thermoluminescent detectors and a PIN diode. Four rads at a meter is

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14. ABSTRACT

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15. SUBJECT TERMS

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measured. The PIN diode waveform scales with the current and voltage waveforms.

III. SPOT SIZE MEASUREMENTS

Spot sizes were measured with two techniques: roll bar and resolution target.

A. Roll Bar Method

A roll bar is set up between the diode and a film cassette or a storage phosphor. The roll bar is a thick [10 cm] piece of tungsten in the shape of an L. The facing surfaces of the L are machined with a 1-m radius, to simplify alignment. Each leg of the L is 16 cm long. The shadow cast by the roll bar is recorded on the film or storage phosphor.

The film cassette is loaded (starting with the material closest to the radiation) with 20 mils of lead, Fuji industrial x-ray film [150 NIF], 20 mils of lead, Kodak Industrex AA400 film [100 NIF}, 40 mils of lead. The loading sequence ensures a wide dynamic range.

By way of illustration, assume an ideal x-ray spot that is circular and of uniform intensity, as in Figure 2. The image produced by an ideal roll bar is the same as that produced by an opaque half-plane. As a point is moved from shadow to light, the shape of the intensity curve produces the step response function of Figure 3.

The step response function is differentiated in space to yield the line spread function of Figure 4. The line spread function contains spatial frequency information about the original x-ray source. This information can be recovered by performing a Fourier transform on the line spread function, shown in Figure 5.

The spot size is defined by the 50% point on the modulation transfer function curve. The inverse of the spatial frequency, divided by 1.4, gives the spot diameter.

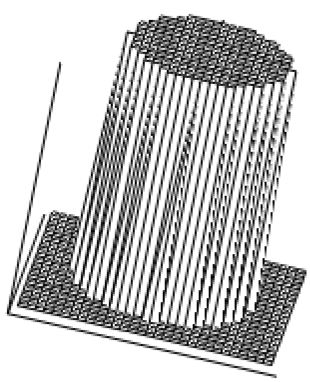

Figure 2. Point spread function of a circular spot with uniform intensity.

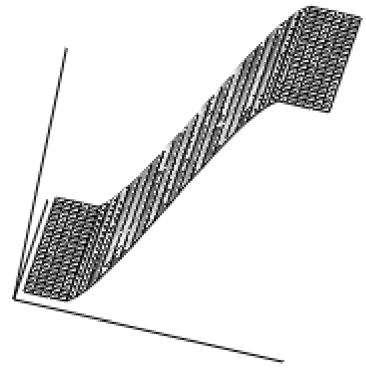

Figure 3. Step response function of the circular spot.

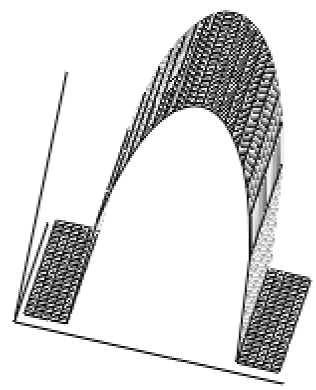

Figure 4. Line spread function of the circular spot.

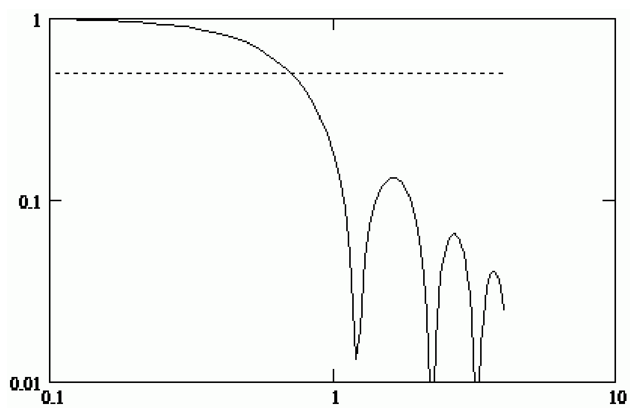

Figure 5. Modulation transfer function of the circular spot, plotted on logarithmic scales.

The modulation transfer function for three easily modeled beam profiles is shown in Figure 6. All have a 1-mm diameter spot size. (At higher spatial frequencies, the Bennett curve lies above the gaussian curve.)

B. Roll Bar Results

Cygnus was operated at 2.25 MV with 0.5-mm diameter gold rods and tapered 0.75-diameter tungsten rods. Although gold rods produced smaller spots, reliability of diode operation was compromised and a few misfires resulted. Tungsten rods produced slightly larger spots, but high reliability, leading to a decision to use tungsten rods for radiography.

Data were obtained for scans across the shadows cast by the X and Y legs of the L-shaped roll bar and for both sets of film. Some results are shown in Figures 7 and 8.

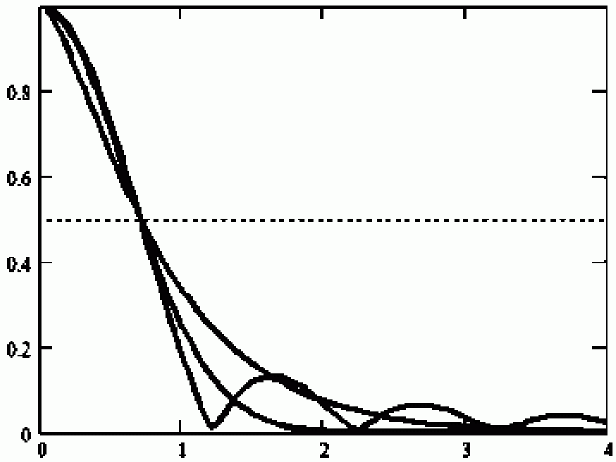

Figure 6. Modulation transfer functions for circular, gaussian and Bennett profile x-ray spots.

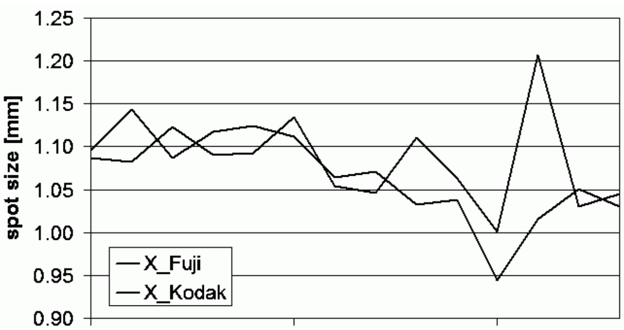

Figure 7. Spot size by shot for 0.5-mm diam gold rods.

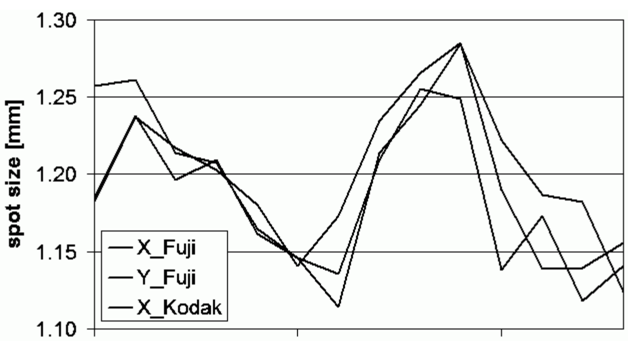

Figure 8. Spot size by shot for 0.75-mm diam tungsten rods.

The spot diameter for gold rods was 1.08 mm [+-0.05 mm]. The spot diameter for tungsten rods was 1.19 mm [+-0.05 mm]. There was no significant difference between X and Y spot sizes or between the film types.

C. Resolution Target Method

A second method of analyzing spot size uses a resolution target, shown in Figure 9. The resolution target simulates passing the x-ray source through a sinusoidal spatial filter. The resulting image is characterized by a modulation ratio of maxima and minima in the intensity.

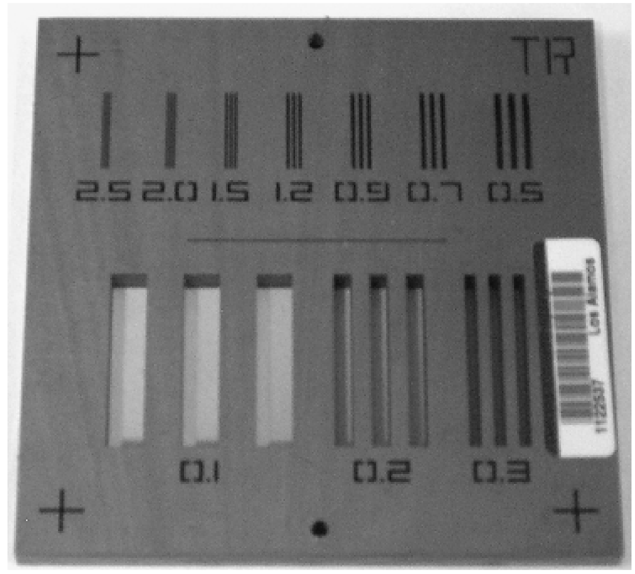

Figure 9. Resolution target, marked in lines per mm.

The pictured resolution target has a rectangular pattern. The target used in the Cygnus experiments was fabricated from 3-mm thick tungsten, 8 cm square. Patterns were obtained using film and storage phosphor.

Analysis was performed by matching synthetic radiographs of circular x-ray sources with the experimental results and comparing modulations, defined as the difference in maximal and minimal intensities divided by the sum of intensities.

Another analysis technique uses a deconvolution of the image and resolution target to recover the x-ray spot characteristics.

The analysis of data using the resolution target method has not progressed as far as the roll bar method. Results so far indicate that the two methods agree.

D. Resolution Target Results

Figure 10 shows experimental results from a 0.75-mm diameter tungsten rod. The modulation decreases as the spatial frequency increases.

IV. FEBETRON 705

The Febetron 705 is a commercially produced x-ray generator, rated at 2.3 MV and 500 millirads at a meter, depending on the diode used. A demountable tube is available, allowing the use of small, expendable anodes. This capability offers the promise of engineering new diode configurations for the Febetron 705 that reduce the spot size. Earlier experiments with a standard diode indicated that the Febetron 705 produced a 9-mm diameter spot size. Our goal is to achieve a 1-mm-scale spot size, comparable to Cygnus.

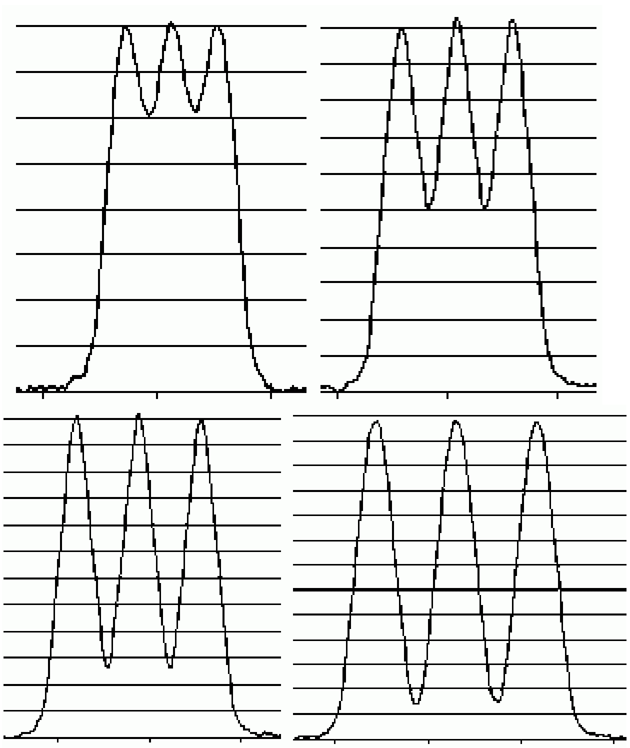

Figure 10. Resolution target images. From left to right and top to bottom: 1.5, 1.2, 0.9 and 0.7 line pairs per mm.

Currently, the Febetron 705 is installed in a laboratory, and equipped with a new flange set that allows experimenters to operate with a standard diode tube, demountable diode tube or resistive load. A common diagnostic set is available. A voltage monitor of the E-dot type came as original equipment and has been calibrated against a voltage divider, consisting of a liquid resistor and current viewing resistor, in series. A current monitor of the Rogowski type is mounted in a flange common to all load configurations. We have the ability to monitor voltage and current characteristics of new diode designs, an essential element in understanding and optimizing performance.

A key feature of the Febetron 705 is the rapid shot rate with standard diodes. Cygnus can produce three rod pinch shots per day, whereas the Febetron 705 can produce dozens of shots per day. Diagnostic issues associated with Cygnus - such as spot size, dose and energy spectrum – are being addressed.

Figure 11 shows the voltage pulse shape of the Febetron 705 with a standard diode tube. FWHM pulse width with a 420-ohm resistive load is 80 ns. FWHM pulse width with the diode is 25 ns.

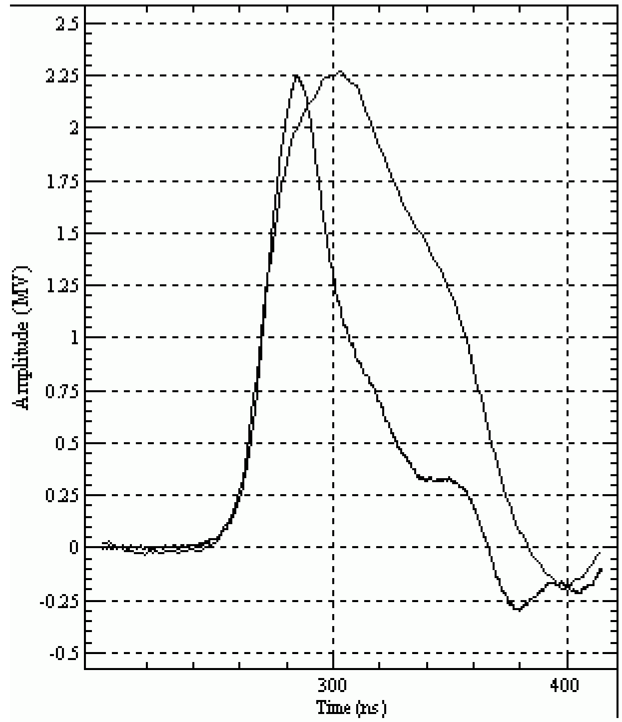

Figure 11. Febetron voltage pulse with a 420-ohm resistive load and with a standard diode.

V. SUMMARY

Cygnus has been operated at 2.25 MV, producing 4 rads at a meter with a 1.2-mm diameter spot size, as determined by roll bar measurements. The second Cygnus x-ray generator is also operating at Titan-PSD. Radiographic experiments are anticipated within the year.

A Febetron 705 has been equipped to pursue issues with the Cygnus x-ray generator and small spot size development.

VI. REFERENCES

[1] J. R. Smith, et al, “Performance of the Cygnus X-ray Source”, 14th International Conference on High-Power Particle Beams, 2002, p. 135.

[2] G. Cooperstein, et al, “Theoretical Modeling and Experimental Characterization of a Rod-pinch Diode,” Physics of Plasmas **8**, 4618-4636, 2001.

VII. ACKNOWLEDGEMENTS

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