Filtered X-ray Diode Diagnostics fielded on the Z-accelerator for Source Power

Measurements*

G. A. Chandler, C. Deeney, M. Cuneo, D. L. Fehl, J. S. McGurn, J. L. McKenney¹, J. Mills¹, R. B. Spielman, K.W. Struve², J. A. Torres*

Sandia National Laboratories, Albuquerque, NM 87185-1196

¹KTECH Corp., 901 Pennsylvania Ave. NE, Albuquerque, NM

²Mission Research Corporation, Albuquerque, NM 87106

RECEIVED
JUN 08 1998
OSTI

Filtered x-ray diode, (XRD), detectors are used as primary radiation flux diagnostics on Sandia's Z-accelerator, which generates nominally a 200 TW, 2 MJ, x-ray pulse. Given such flux levels and XRD sensitivities the detectors are being fielded 23 meters from the source. The standard diagnostic setup and sensitivities are discussed. Vitreous carbon photocathodes are being used to reduce the effect of hydrocarbon contamination present in the Z-machine vacuum system. Nevertheless pre- and post-calibration data taken indicate spectrally dependent changes in the sensitivity of these detectors by up to factors up to 2 or 3.

(Presented on 7 June 1998)

INTRODUCTION

Z is a 60-TW/5 MJ electrical accelerator which has been developed at Sandia National Laboratories as a driver for fast Z-pinch implosions. Z-pinches have demonstrated the capability for efficiently generating high power x-ray radiation sources and with Z have demonstrated the capability of generating x-ray powers over 200 TW's and x-ray energies 2 MJ's¹. The radiation sources produced by Z are being used in high energy density physics, radiation effects and inertial confinement fusion experiments². Z is a cylindrically symmetric pulsed power accelerator in which stored energy is compressed

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

June 2, 1998

2:13 PM

1

ph

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

in time and space and delivered to a Z-pinch load through magnetically insulated transmission lines and a vacuum convolute. The details on the operating characteristics of Z can be found in references 1 and 3. A typical Z-pinch load used to produce large amounts of soft x-ray radiation (100-1500 eV) is a tungsten wire array 1 to 2 cm tall consisting of ~270 wires, 5 μm thick imploded from an initial radius of 1 to 2 cm. The wire array implodes under a peak drive current of ~20 MA. The final stagnated linear pinch is typically 0.75-1 mm in radius and produces a radiation pulse 5-10 ns full width at half maximum, (FWHM), with output powers of 100-200 TW and output energies of 1.5-2 MJ. Estimated pinch temperatures of 180-250 eV are produced.

An array of filtered x-ray diode (XRD) detectors are one of the primary x-ray diagnostics probing the radiation from these sources. These detectors have the advantage of being large area, fast response time detectors which have appropriate sensitivities for viewing the large flux from the Z-pinch and which can be readily calibrated at low flux x-ray source facilities. The setup and characterization of these detectors as fielded on Z for pinch power measurements will be discussed in the following sections. Other diagnostics used on Z are discussed in other papers presented at this conference.^{4,5,6,7}

II. THE X-RAY DIODE DETECTORS

The biplanar XRD detectors used consist of a photocathode and an anode mesh built into an N-connector housing as shown in Fig. 1. These detectors are built at Sandia and are similar in design to those discussed in ref. 8 and 9. The photocathode consists of a diamond polished vitreous carbon disk¹⁰ (12.5 mm in diameter, 2 mm thick). The carbon disk is silver epoxied to a gold-plated copper or nickel stalk and acts as the center conductor for the modified N-connector. The carbon disks are polished to an rms roughness of 500 Å under a procedure using a diamond grit in a hydrocarbon, ethylene Glycol, slurry. The photocathodes final cleaning is with 100% ethanol in which they are allowed to soak for 24 hours. This procedure effectively yields a detector which has a

response dominated by carbon, oxygen and hydrogen photoemission. Vitreous carbon is used to reduce the effect of hydrocarbon contaminants present in the Z vacuum environment on the photocathode sensitivity.

In addition to the photocathode a number of other components are also required. Teflon spacers insulate the photocathode (biased at -1000 volts) from the body of the detector and the electroformed nickel anode mesh¹¹ which are at ground potential. The mesh is 90% transmissive, 5.08 μm thick and has a rectangular pattern with grid lines 20 μm wide spaced 340 μm apart. The mesh is separated 0.25-0.5 mm from the photocathode surface which yields a Child-Langmuir limited current flow (reduced by the current induced voltage drop in the cable) of 20-50 Amps/cm².¹² Nonuniformities in the field due to the mesh size and spacing from the anode were modeled using a two dimensional field solver. The calculations show the field strength on the photocathode is only ~65% of the applied field for a uniform 0.25 mm gap spacing. This reduces the charge saturation currents to 12-28 amps/cm² which is 2-4 times the typical peak detectors currents of ~5 amp/cm². The last component of the XRD is a limiting aperture placed above the anode mesh with an ID of 3-8 mm to define the detector solid angle.

The intrinsic time resolution of these detectors is set by the transit time for the photoelectrons to cross the A-K gap and the fall time is given by the RC time constant for the diode¹³ For these diodes the electron transit times are ~ 50 ps. The detector capacitance is ~1.4 picofarads yielding a fall time of ~70 ps. The time resolution measured by direct irradiation with a xx ns FWHM fourth harmonic pulse from a Nd Yag laser is better than xx GHz based on the risetime of the signal as measured by a 3 GHz Tektronics SCD5000 digitizer.

III. Detector Fielding Configuration

A set of five detectors is mounted on N connector feedthroughs in a commercially-available, vacuum-tight housing coupled through a modified six inch conflat flange as

shown in Fig. 2.¹⁴ The housing supports the filters above the photocathodes and separates them from each other by a set of neodymium-iron-boron magnets. The 3.5 kilogauss field present in the gap over the 1.2 cm distance between them blocks photoelectrons from the x-ray filters and other stray electrons with energies below 3 MeV from being detected.

The detectors are electrically coupled to fast, high bandwidth, (1 GHz) Tektronics 684's or 645's digitizers, as shown in Fig. 3. The detectors are capacitively coupled to the digitizers through a high bandwidth Sandia designed insertion unit.¹⁵ This single-ended operating mode for the detectors minimizes the electrical noise and reduces the complexity of the detectors at the expense of slight signal degradation due to RC droop and impedance mismatch in the insertion unit. The insertion units use an chip capacitor¹⁶ with a measured 18 nF capacitance leading to an RC time constant of 1.8 μ s yielding a negligible droop correction, ~1%, on the peak of a typical signal. The bandwidth of the insertion unit was measured at 2 GHz based on the change in the risetime of a measured input pulse.

The detectors are coupled to bias boxes through 20 feet of 0.5" Helix coaxial cable, (Andrews LDF4-50A), and from the bias boxes to the digitizers through 8 feet of RG-9914. The calculated bandwidth for the cables is greater than 8 MHz with a risetime of ~0.04 ns. Barth attenuators and power tees¹⁷ having a specified bandwidth of 20 GHz are used to split each pulse to two scopes for greater dynamic range on the measurements. The measured system bandwidth is 600 Mhz and is dominated by the digitizers. The timing between the different XRD channels has been measured to be within 280 ps. Signal degradation due to attenuation in the cables was observed to be 4% for a representative signal with a 1.1 ns risetime and a 3.7 ns FWHM.

The detectors are placed 23 meters from the center of the accelerator along a line-of-sight, (LOS), pipe inclined at 88° from the pinch axis. The LOS pipe contains debris and x-ray baffles. The XRDs are also protected against debris by a commercially available,

open to closed, pneumatically-operated fast valve¹⁸ having a closure time of ~ 1 ms. The detectors typically view the stagnating pinch through one of nine slots in the return current can along a LOS as shown in Fig. 4. Efforts to minimize viewing re-radiation from regions other than the pinch is made by collimation near the source.

III. Detector Sensitivities and Calibrations

The response of the XRD channels is determined by the spectral sensitivity of the photocathodes and the transmission of x-ray filters. The nominal responses of the detectors are shown in Fig. 5. The bandpass of these filters have been chosen to bound the flux from a pinch with a nominal brightness temperature of 200-250 eV. The vitreous carbon photocathodes and a set of x-ray filters have been calibrated at the National Synchrotron Light Source, (NSLS), facility at Brookhaven National Laboratory typically between 150 and 5700 eV. The complete set of filters have been characterized by alpha spectroscopy energy loss measurements for thickness, a relatively easy measurement to make, so that x-ray calibrations of filters which have been characterized at the NSLS can be cross referenced to them. The photocathode response data is fit to mass absorption coefficients. This sensitivity is then multiplied with a fit to the filter calibration data to define the detector response. The typical one sigma error bars quoted on the NSLS XRD calibrations are between 10 – 15% and for filter transmission calibrations 5%. The overall error for the XRD sensitivities has been estimated at 20% and typically dominates the error in the measurement of the peak pinch power.

IV. Data unfolding for pinch power measurements

The defining equation for the detector signals due to the source flux is given by:

$$V_i(t) = Z A_s \cos(\theta) f_s \frac{A_d}{d_s^2} \int_{E_{min}}^{E_{max}} S(E,t) R_i(E) dE \quad \text{eq. 1}$$

Where V_i is the detector voltage for the i th channel, Z is the input impedance of the scope (50 ohms), $A_s \cos(\theta)$ is the projected pinch area along the LOS, f_s is the fraction of the source area viewed, A_d is the detector area, d_s is the source to detector distance, S is the source flux (watts/(sr-cm²-eV)), and R is the detector response in amps/watts as a function of photon energy.

The detector signals are unfolded for the source flux by approximating the source spectrum as a linear combination of histogram basis functions.^{19,20} Thus $S(E,t)$ is represented as:

$$S(E,t) = \sum_{j=1}^N S_j(t) B_j(E) \quad \text{eq. 2}$$

where B_j represents unit histograms and S_j are the coefficients for the functions. We use 5 functions defined to be contiguous with bin boundaries taken at 137, 284, 513, 1020, 1500 and 2300 eV mostly determined by filter K-edges. The low energy boundary is defined where the sensitivity of the channel falls to ~ 1% of its peak response. The upper boundary is set large enough so that the emission from a Plankian spectrum of 250 eV is recovered to within a few percent. With this representation for the source spectrum equation 1 can be unfolded to yield an approximation for the source spectrum. These unfolds are used principally to estimate the spectrally integrated peak x-ray power in the spectral range, 137-2300 eV. Within this energy range the total emitted power into 4π steradians in the pinch, assuming a cylindrical Lambertian radiator, is given by:

$$P_{tot}(t) = \pi^2 A_s \int_{E_{min}}^{E_{max}} S(E,t) dE \quad \text{eq. 3}$$

The accuracy of the unfold representation of the spectrum is tested against simulations of blackbody sources. As shown in figure 6 the total flux unfolded from these simulations is within 10% of the flux in a blackbody in this interval for blackbodies between 100-225 (250 needs to be done) eV, which is consistent with the peak pinch brightness temperatures observed.

The energy spectrum at peak power unfolded from these detectors for the target is shown in Fig. 7. As can be seen from this figure the observed spectrum is not well represented by a Plankian spectrum having a much flatter spectral shape. This has been attributed to temperature gradients in the plasma.^{21,22,23} The total radiated flux at this time, as inferred from the XRD's, is 220 TW's, equivalent to a 240 eV blackbody for a measured pinch diameter of 1.0 mm and 2 cm long. Given the 20% uncorrelated errors for the input response functions, which dominate the errors in the data, a $\pm 12\%$ error is assigned to the total peak power. A time-resolved unfold can be done to yield the source power as a function of time as shown in Fig. 8. The time history of the x-ray pulse is seen to have a 5 ns risetime with a FWHM of 4 ns.

V. XRD Calibration Stability Issues.

The XRD's have been pre and post calibrated at the NSLS to observe the change in their response to fielding on the Z accelerator. As shown in Fig. 9 dramatic differences in the response occur over time. Presently we are working to uncover the sources for the observed changes in the response. We have seen the development of a thin, xxx Å hydrocarbon film over time on the photocathodes. Also physical changes in the photocathode surface have been observed as pits and/or 'burn' marks. Speculation as to whether they are due to ion or plasma etching of the photocathode surface have been made. In order to improve the stability of these detectors we are pursuing a number of techniques to improve the vacuum environment, presently set at $\sim 5\text{e-}6$ torr, of the detectors. These include adding cryopumps in addition to the turbo pumps presently used, to improve the physical isolation from the main accelerator vacuum by using closed-open-closed fastvalve configurations and thin vacuum tight membranes, and by heating the photocathode surface.

VI. Conclusions

XRD detectors have been used to infer time dependant x-ray flux from the highly energetic Z-accelerator with measured peak powers over 200 TW. The detector system has a 600 Mhz bandwidth which is dominated by the digitizers. Detector calibrations using the NSLS yield dominate the error estimates and typically yield a $\pm 12\%$ error on the total flux measurement. Issues exist with the photocathode stability and are being addressed to yield a more robust detector system.

ACKNOWLEDGEMENTS

This work would not have been possible without the support and efforts of the Z operations crew particularly the diligent efforts of Tom Dinwoodie and Jeff Slopek in Z data acquisition.

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of under Contract No. DE-AC04-94AL85000.

¹ R.B. Spielman, et. al. Physics of Plasmas, No. 5, 2105 May (1998)

² Keith Matzen's paper?

³ R.B. Spielman, et. al., Proceedings of the 9th IEEE Pulse Power Conference, Albuquerque, NM, edited by R. White and K. Prestwich (Institute of Electrical and Electronics Engineers, New York, 1995), p. 396.

⁴ D. L. Fehl, D.J. Muron, R.J. Leeper, G.A. Chandler, C. Deeney, and R.B. Spielman., These proceedings

⁵ R.B. Spielman, C. Deeney, D.L. Fehl., D.L. Hanson, N.R. Keltner, J.S. McGurn, and J.L. McKenney, These proceedings

⁶ T. Nash, J. Seamen, M.S. Derzon, G.A. Chandler, D. Fehl, R. Leeper, M. Hurst, D. Jobe, J. Torres, J. Seaman, S. Lazier, T. Gilliland and J. McGurn, These proceedings.

⁷ M. Derzon, These proceedings

⁸ R. B. Spielman and J. P. Anthes, "Low Energy X-ray Diagnostics", AIP Conference Proceedings No. 75. 278 (1981)

⁹ R. H. Day, P. Lee, D. J. Nagel, J Appl. Phys. 52 (11) November (1981)

¹⁰ Source of the Vitreous Carbon Photocathodes.

¹¹ Lebow Company, 5960 Mandarin Ave., Goleta, CA 93117, 805-964-7117.

¹² R. B. Spielman and J. P. Anthes, "Low Energy X-ray Diagnostics", AIP Conference Proceedings No. 75. 278 (1981)

¹³ P. B. Lyons, AIP Conference Proceedings No. 75 59 (1981)

¹⁴ Team Specialties, 11030 Cochiti SE, Albuquerque, NM 87123, 505-291-0182

¹⁵ R.B. Spielman, L.E. Ruggles, R.E. Pepping, S.P. Breeze, J.S. McGurn and K.W. Struve, Rev. Sci. Instrum. 68, page#? (1997)

¹⁶ Wright Capacitors, 3009 S. Orange Ave., Santa Anna, CA 92707, 714-546-2490, Part #WC2725R183KD102.

-
- ¹⁷ Barth Electronics, Inc. 1300 Wyoming St. Boulder City, NV 89005, 702-293-1576
¹⁸ Spectral Precision Inc, 1087 Fife Ave, Palo Alto, CA 94303,
¹⁹ D.L. FehI, G.A. Chandler, F. Biggs, R.J. Dukart, A.R. Moats, and R.J. Leeper, Rev. Sci. Instrum. 68, 843 (1997)
²⁰ D. L. FehI, F. Biggs, Rev. Sci. Instrum. 68, 890 (1997)
²¹ J.P. Apruzese, et. al., IEEE Trans. Plasma Sci. Aug. (1998)
²² C. Deeney, et. al., Phys. Rev. E, 51, 4823 (1995)
²³ C. Deeney, et. al., Phys. Rev. E., 56, 5945 (1997)

Figure Captions

FIG. 1. Drawing showing the components of the Sandia XRD detectors. Components are: 1) N Connector Body, 2) Teflon insulator, 3) Gold-plated copper or nickel stalk, 4) Vitreous Carbon Photocathode, 5) Teflon insulator, 6) Nickel Anode Mesh, 7) Limiting Aperture, 8) Locking Nut

FIG. 2. Five channel XRD detector housing. In this exploded view of the assembly one can see, from left to right the six major components: 1) The 6" vacuum housing with 5 N-connector feedthru's; 2) An XRD assembly; 3) Sweeper magnet support assembly; 4) Sweeper magnet assembly; 5) Filter support; 6) Locking assembly

FIG. 3. Electrical diagram showing the XRD fielding setup. The DC bias is typically -1000 kV, The total biasing resistance, R_b , is xx ohms including xx ohms in the bias box and xx ohms inline to the DC voltage supply. The bias box capacitor, C_b , is 18 nF and the impedance of the cables and scopes are matched at 50 ohms.

FIG. 4. View of stagnating pinch geometry

FIG. 5. XRD channel sensitivities obtaining combining a vitreous carbon photocathode with the following filters: 1) $4\text{ }\mu\text{m}$ Kimfol; 2) $1\text{ }\mu\text{m}$ Vanadium; 3) $0.75\text{ }\mu\text{m}$ Zinc and $0.5\text{ }\mu\text{m}$ Parylene_N; 4) $8\text{ }\mu\text{m}$ Beryllium and $1\text{ }\mu\text{m}$ of Parylene_N; 5) $10\text{ }\mu\text{m}$ Beryllium and $0.8\text{ }\mu\text{m}$ of Vanadium.

FIG. 6. Comparisons of the flux from blackbody sources to unfolded simulations of these sources.

FIG. 7. Unfolded Energy spectrum from a pinch at peak power for two Z-shots. Shot 182 is a more typical spectrum. Shot 179 had the highest peak power observed, 220 TW while shot 181 had 185 TW. As is seen in the plot neither spectrum is Plankian in character.

FIG. 8. Time history of unfolded pinch power for shots 179 and 181 indicating nominally a 5 ns risetime, a 4 ns FWHM and a 20 ns low power tail to the pulse.

FIG. 9. Spectrally resolved calibrations of vitreous carbon photocathodes fielded on Z reveal dramatic changes in there response over time.

Fig. #1

Figure #2

Fig. #3

Figure #4

Figure #5

Figure #6

Figure #7

Figure #8

M98005528

Report Number (14) SAND--98-0394C
CONF-980605--

Publ. Date (11) 199806
Sponsor Code (18) DOE/DP, XF
UC Category (19) UC-712, DOE/ER

19980702 009

DTIC QUALITY INSPECTED 1

DOE