CONF-860665--10

Received by OSTI

JUL 1 4 1986

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.

UCRL- 93750
PREPRINT

BEAM PROFILE MEASUREMENTS ON THE ADVANCED TEST ACCELERATOR USING OPTICAL TECHNIQUES

Y. P. Chong, R. Kalibjian, J. P. Cornish,
J. S. Kallman and D. Donnelly

This Paper was Prepared for Submittal to
BEAMS '86 Conference
Kobe, Japan
June 9-12, 1986

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

UCRL--93750

DE86 012813

BEAM PROFILE MEASUREMENTS ON THE ADVANCED TEST ACCELERATOR USING OPTICAL TECHNIQUES

Y. P. Chong, R. Kalibjian, J. P. Cornish,
J. S. Kallman, and D. Donnelly

Lawrence Livermore National Laboratory
University of California
Livermore, CA 94550

Abstract

Beam current density profiles of ATA have been measured both spatially and temporally using a number of diagnostics. An extremely important technique involves measuring optical emissions from either a target foil inserted into the beam path or gas atoms and molecules excited by beam electrons. This paper describes the detection of the optical emission. A 2-D gated television camera with a single or dual micro-channel-plate (MCP) detector for high gain provides excellent spatial and temporal resolution. Measurements are routinely made with resolutions of 1 mm and 5 ns respectively. The optical line of sight allows splitting part of the signal to a streak camera or photometer for even higher time resolution.

Introduction

A critical parameter of the Advanced Test Accelerator (ATA) [1] electron beam is the current density profile. Several techniques [2] have been investigated on the Experimental Test Accelerator (ETA) such as using a Faraday cup and x-ray detection from a high-Z target. This paper describes the technique of detecting prompt optical emissions generated by beam electrons striking a target foil inserted into their path in vacuum. In a gaseous environment some of the beam-excited atoms and molecules decay radiatively on time scales < 1 ns. Detection of these prompt emissions allows measurement of beam current density. Gated, intensified 2-D television cameras determine 2-D profiles for each individual pulse in contrast to other scanning techniques that require multiple pulses. A streak camera has also been deployed to scan time scales < 1 ns.

General Purpose Probe

Figure 1 shows a typical application of the general purpose probe (GPP) which is mounted on a large pump-section flange. Optical emissions are detected in a perpendicular direction through a line of sight (LOS). The GPP inserts and rotates the target foil to an appropriate angle while the ATA beam is turned off. The front side where the beam strikes the foil can be viewed as well as the rear side.

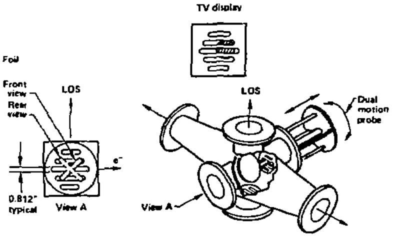

Fig. 1. ATA diagnostics - optical emissions generated by electron beam striking inserted foil.

Optical Emission Detection

A block diagram of the optical diagnostics system is shown in Fig. 2. Optical signals from a foil or gas are transmitted through a viewing port at the beamline and directed by a series of turning mirrors to exit through a sleeve at the tunnel ceiling. Outside the tunnel the signal is relayed to a telephoto lens mounted on a gated, intensified 2-D tv camera (Fairchild CCD-3000F). The optical image is digitized by a datacube frame grabber and read out digitally for processing and storage on a computer. Dual LOSs may be combined using a beamsplitter in front of the telephoto lens in order to reduce the number of camera stations. An additional option is to place a 4-port coupler between the lens and camera. This consists of a beamsplitter with four orthogonal ports. Two opposing ports connect the camera to the lens.

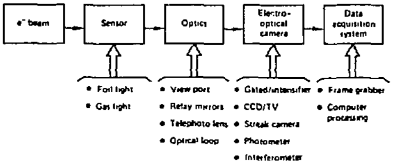

Fig. 2. Block diagram of ATA optical diagnostic.

The orthogonal ports allow a number of options. A streak camera can be coupled to the LOS for fast time resolution, or an optical-loop channel can be inserted into the image space of the telephoto lens for an optical transit-time delay. Alternatively, two LOSs with their respective telephoto lenses for different object distances can be combined into one camera system through the 4-port coupler. When spatially-integrated intensity is desired, a photometer can replace the streak camera. For electron density measurements an interference pattern can be acquired by the frame grabber.

A typical setup is shown in Fig. 3. The high background radiation level at ATA precludes camera placement inside the ATA tunnel without substantial shielding. Location of the camera outside the tunnel also allows easy personnel access during run time.

The imaging camera consists of a 1.8 cm dia MCP proximity-focused, image intensifier tube that is coupled fiber-optically to a charge-coupled-device (CCD) sensor (Fig. 4). The 1.14 cm length CCD chip is scanned internally to provide the composite video signal to the acquisition system. Monitors display video frames via a memory board on a realtime basis to enable instant feedback during the experiment.

The MCP intensifier tube can be gated electrically to a shutter speed of 4 ns. The nominal gain is 1000 but it can be increased to 12,000 by pulsing the MCP at a higher voltage. However, the photocathode gate width must not exceed 5 ns in order to prevent serious degradation in spatial resolution by ion feedback to the photocathode.

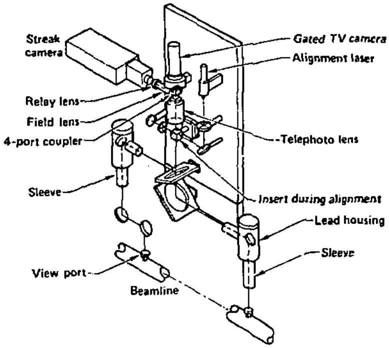

Fig. 3. Typical optical LOS and detection system. Dual LOSs are combined at one camera station. Lead housing at top of tunnel sleeve provide radiation shielding.

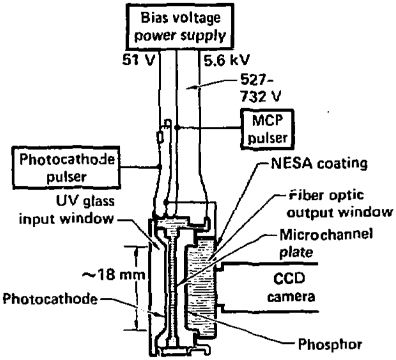

Fig. 4. Gated image intensifier tube with fiber-optic coupling to CCD camera. The photocathode pulser provides a gate width of 5 ns.

The ion feedback mechanism is controlled critically by the photocathode pulse width whereas the electron gain enhancement is independent of it. Thus, a photocathode pulse width of 100 ns at the higher MCP voltage can give electron gains above 200,000. However the spatial resolution is severely degraded and a mottled image pattern is obtained. The ion feedback generation occurs primarily in the cathode-MCP region of the tube. To prevent the ions from generating further electron emission from the photocathode, it is important to turn off the electric field within 5 ns during high-voltage pulsing of the MCP.

In general the contrast transfer function (CTF) decreases with increasing MCP voltage. The spatial resolution is 6 lp/mm at 100 electron gain and 20% CTF for a 50%-level screen brightness (Fig. 5). The resolution at 1000 electron gain is 5 lp/mm. For certain applications, the intensity level is attenuated preferably through electronic control rather than optically with neutral density filters. In conjunction with the MCP gain control, the phosphor screen voltage can be varied to control the brightness gain. The spatial resolution remains constant when the phosphor voltage is reduced and the input intensity is increased to maintain a 50%-level screen brightness. The phosphor screen brightness has a range of 15. Coupled with the MCP range of 1000, the overall camera brightness gain has a electronically controlled range of 15,000.

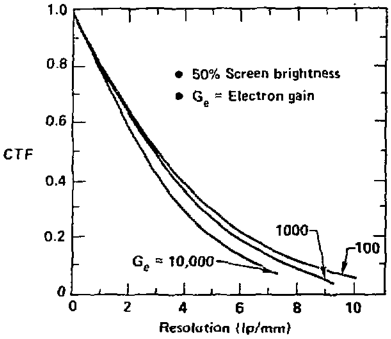

Fig. 5. Spatial resolution in the gated (5 ns) intensified CCD camera.

Foil Optical Emission

When a thin metal foil is struck by a relativistic electron beam in vacuum, prompt optical emission is observed for the duration of the beam pulse. The emission source is believed to be transition radiation [3]. This feature leads to a useful diagnostic for measuring the spatial and temporal behavior of the electron beam. Measurements were made in early 1983 to compare the time histories of the ETA beam current to the spatially-integrated optical emission from a thin titanium foil. Good agreement was obtained as is seen in Fig. 6, which shows corresponding features: an initial small step, a large peak separated from a second double peak by a deep valley, a shoulder on the trailing edge and ending in a long tail. The distinctive current levels correspond to 1, 4 and 7 kA. Relative magnitudes agree to only within 20% because the data were taken for different pulses. Although ETA is repetitively reproducible, changes of up to 20% are not unexpected.

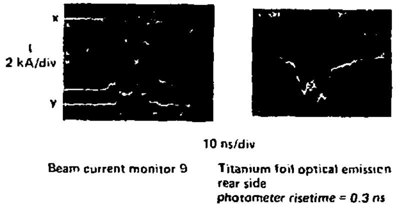

Fig. 6. Time-history comparison of titanium foil light-emission to ETA beam current monitor in vacuum. The data were taken for different pulses.

Passage of the electron beam through the high-Z titanium foil causes degradation in beam emittance due to electron scattering in the foil. At interfaces between vacuum and gas sections, mechanical stress arising from the high-pressure differential dictates the use of thick low-Z foils such as carbon. Optical emission from carbon has also been observed to be prompt during the beam pulse, but the source of radiation has not been identified at this time. A disadvantage is that the emission intensity is lower for carbon than for titanium. Figure 7 shows a spatial profile of carbon foil emission by the ATA beam. The gate width was 5 ns. By marching the gate through the pulse, spatial profiles for the entire pulse have been obtained [4].

Fig. 7. Spatial profile of carbon foil emission generated by the ATA beam. Gate width = 5 ns. FWHM = 0.4 cm.

Gas Optical Emission

For beam propagation in gas, a nonperturbative diagnostic is to measure optical radiation from gas molecules excited by the electron beam. A LOS and camera system views the ATA beam in a transverse direction. Figure 8 shows a spatial profile of the gas emission for a gate width of 5 ns. The wavelength spectrum covers the range of the S-20 photocathode. At the scanned location, FWHM = 1.8 cm. Multiple transverse LOSs enable beam profile diagnoses at different propagation distances for a single pulse.

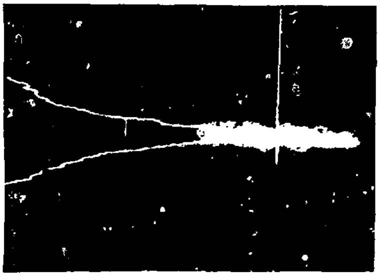

Fig. 8. Spatial profile of gas emission by ATA beam. Gate width = 5 ns. FWHM = 1.8 cm.

Acknowledgments

We wish to express our grateful thanks to the following persons: Dr. Tom Fessenden for initiating this effort, Dr. John Clark for collaboration on ETA data, Bill Weiss, Jr., Drs. F. W. Chambers and K. W. Struve for their contributions, Chuck Jackson and Fred Holdener for mechanical design, John Kinney for practical ideas and technical supervision, Cliff Holmes for probe assembly and test, Vince Farfan and Phil Stephan for technical support. Work performed jointly under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-ENG-48 and for the Department of Defense under Defense Advanced Research Projects Agency ARPA Order No. 4395, monitored by Naval Surface Weapons Center under document number N60921-85-POW0001, and Naval Surface Weapons Center under document number N60921-85-WRW0201.

References

[1] D. S. Prono, IEEE Trans. Nucl. Sci. NS-32, 3144 (1985); R. J. Briggs, Proc. LINAC '84 Conf. Darmstadt, West Germany, 1984; L. Reginato, IEEE Trans. Nucl. Sci. NS-30, 2970 (1983)

[2] Y. P. Chong, E. J. Lauer, J. C. Clark, D. R. Slaughter and T. J. Fessenden, Proc. Fifth International Conf. on High-Power Particle Beams, San Francisco, California, U.S.A., 1983 p.404

[3] L. Wartski, S. Roland, J. Lasalle, M. Bolore and G. Filippi, IEEE Trans. Nucl. Sci. NS-22, 1552 (1975)

[4] Y. P. Chong, G. J. Caporaso, E. J. Lauer, D. S. Prono, F. Rainer, K. W. Struve and J. T. Weir, Sixth International Conf. on High-Power Particle Beams, Kobe, Japan, 1986 (to be published in conference proceedings)