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Y. P. Chong, J. P. Cornish
and D. Donnelly

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Optical diagnostics in the advanced test accelerator (ATA) environment*

Y. P. Chong, J. P. Cornish, and D. Donnelly

Lawrence Livermore National Laboratory
University of California
Livermore, CA 94550Abstract

The ATA is a 50-MeV, 10-kA, 70-ns pulsed electron beam accelerator that generates an extremely harsh environment for diagnostic measurements. Diagnostic targets placed in the beamline are subject to damage, frequently being destroyed by a single pulse. High radiation (x-ray, gamma, and neutron) and electromagnetic interference levels preclude placing components near the beamline that are susceptible to radiation damage. Examples of such components are integrated circuit elements, hydrocarbons such as Teflon insulation, and optical components that darken, resulting in transmission loss. Optical diagnostics play an important part in measuring experimental parameters such as the beam current density profile. A large number of optical lines of sight (LOS) are routinely deployed along the experimental beamlines that use the ATA beam. Gated TV cameras are located outside the accelerator tunnel, because the tunnel is inaccessible during operations. We will describe and discuss the difficulties, problems, and solutions encountered in making optical measurements in the ATA environment.

Introduction

The ATA is a linear induction accelerator¹ that produces a 50-MeV, 10-kA, 70-ns electron beam. It is typically pulsed at 1 Hz. High radiation levels of gamma rays, x-rays, and neutrons are generated during each pulse. Radiation damage restricts severely the type of materials and components that may be placed near or in the beamline. Examples are integrated circuit elements that are destroyed by the electromagnetic pulse, hydrocarbons such as Teflon insulation that eventually turn into powder, and optical windows that suffer radiation darkening. For simplicity, we chose to place all radiation-susceptible components outside the tunnel shield except for components where it was unavoidable such as vacuum-air interface windows. The added advantage was that personnel access to hardware was convenient and in a safe radiation region.

A primary diagnostic involves optical measurement of the electron beam parameters. A brief description of the optical diagnostic is given, followed by measurements of fluorescence induced in a fiber-optic bundle and radiation darkening of a beamline window component.

Optical diagnostics system

The optical diagnostics system² is shown in component form in Fig. 1. Optical emission is generated by the electron beam incident on a target foil inserted into the beam path in vacuum. In a gas-filled region the electron beam induces optical emissions through atomic and molecular excitations. An optical line-of-sight (LOS) system relays the image to the detector, which is located outside the hostile radiation environment. The detector may comprise a gated image-intensifier optically coupled to a CCD TV camera that records a 2-D spatial image. Time resolution of 5 ns is attainable. The detector can be a microchannel-plate photometer that allows nanosecond time resolution of the spatially-integrated optical signal. For a 1-D spatial image with picosecond time resolution a streak camera is used. The digitized image or trace signal is fed into a computer for image processing and data reduction.

Figure 2 shows the logic circuit and timing scheme when the gated intensifier CCD TV camera is deployed. Figure 3 shows an optical system for a dual LOS arrangement with dual detectors. Note the lead housings that shield the outside region from radiation leaking through the sleeve in the tunnel. Many of these optical diagnostic systems (typically with just a single detector) are deployed along the ATA beamline at locations where measurement of the electron beam current density profile is desired. Examples of the foil and gas optical emissions are shown in Figs. 4 and 5 respectively. Further discussions of data utilization are presented in a companion paper.³

Fiber-optic radiation test

A coherent fiber-optic bundle (Dainichi-Nippon 6000 pixel, pure fused silica) was tested for fluorescence and transient darkening in the ATA radiation environment. Figure 6 shows the experimental configuration. The light pulse from a xenon flashlamp was sent through optical filters mounted on a remote-controlled rotatable wheel. The fiber-optic bundle guided the pulse to a microchannel-plate phototube that was shielded against radiation in a lead housing. The fiber-optic cable was laid transversely over the ATA beamline to subject it to radiation. The radiation dosage was measured by placing

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a terminated cable over the beamline and recording the radiation-induced signal. The signal is caused by Compton and pair production electrons produced by radiation incident on the coaxial cable. Struve⁴ has measured the induced signal for various cable types and dose rate. Knowing the calibration factor, the radiation dosage was obtained.

In a preliminary test, the xenon flashlamp was found to be too low in its light output compared to the transient fluorescence induced in the fiber by the electron beam. The fluorescent peak signal was three times higher than the flashlamp peak signal at the same phototube voltage setting. Further tests on radiation darkening of the fiber are dependent on finding a brighter light source.

Radiation-induced fluorescence

The fluorescence induced in the fiber cable was measured with the flashlamp turned off. Each fluorescent signal detected by the phototube was recorded as a function of time on a Tektronix 7912 transient digitizer. The integrated signal is plotted versus shot number in Fig. 7. Initially the electron beam was tuned for minimum radiation spill. For the later shots the beam was tuned to dump more current in the region of the fiber to increase the radiation level.

The fluorescent signal is plotted as a function of radiation dose in Fig. 8. The signal is seen to increase almost linearly with the radiation dose rate up to a maximum of about 2500 rads/pulse, beyond which it decreases. The peak indicates the radiation level beyond which the fiber suffers darkening and, therefore, a large transmission loss.

Figure 9 shows the fluorescent signal normalized to the dose rate, plotted vs total dose rate. Disregarding the two dips for the moment, the data shows an almost flat portion followed by a steep decline until it flattens out at the bottom. We offer the following explanation: The flat part indicates no permanent darkening has occurred out to the shoulder. Beyond the shoulder permanent darkening sets in until the flat bottom is reached where no additional darkening is possible. The dips are probably due to recovery from transient darkening effects. Since the shots were not taken on a constant time interval, the dips indicate the shots that were taken too soon one after another. There was insufficient time to recover fully from transient darkening.

Radiation darkening of optical window

Each LOS views the beam through an optical window that is located about a foot from beamline axis. Ordinary or low-grade quartz suffers more than 50% transmission loss after 1-2 h runtime, depending on the radiation level. Thus far, the material most resistant to darkening was found to be high-grade quartz (Corning 7940). It was observed to remain clear visually after days of operation. However, calibration measurements of a window removed after about three months of exposure show substantial transmittance loss in the UV region. Figure 10 shows the transmittance decreasing gently from 800 nm to 500 nm, where the loss becomes more pronounced. Below the shoulder at 340 nm, the loss is increasingly severe with the transmittance dropping to 0.4 at 250 nm. The surface exposed to vacuum exhibits a lower reflectance than the surface facing air. This is attributed to surface cleaning in vacuum by beam irradiation. A careful measurement was initiated recently, which obtained a transmission curve for a new window. It was placed near the radiation-detection cable and the radiation level was recorded for the duration of exposure. The window transmission vs wavelength was measured again. This procedure was repeated three times over a period of three months. Figure 11 compares the first and final curves. A loss of 1% is observed from 200 nm to about 340 nm beyond which no degradation is seen. The total radiation dose was 51 krad. It is possible that the long time interval between runs permitted a substantial degree of recovery. Further measurements with increasing dosage will be conducted.

Conclusion

The hostile environment of ATA has adverse effects on materials for optical diagnostics. At ATA, the choice has been to place a minimal number of radiation-sensitive components inside the tunnel. The loss in light collection efficiency is compensated by the ease of personnel access to equipment. Radiation tests on a fiber-optic bundle show that fluorescence is the dominant obstacle to its deployment in the accelerator vicinity. Material darkening is the next problem, with Corning 7940 quartz performing best so far.

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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, R. Kalibjian, J. P. Cornish, J. S. Kallman, and D. Donnelly, "Beam Profile Measurements on the Advanced Test Accelerator using Optical Techniques", Proc. Beams '86 Sixth Int. Conf. High-Power Particle Beams, Kobe, Japan, 1986.

3. F. W. Chambers, J. S. Kallman, M. E. Slominski, Y. P. Chong, J. P. Cornish, and D. Donnelly, "Utilization of optical image data from the advanced test accelerator (ATA)", accompanying paper 787-21 at this SPIE Conf.
4. K. W. Struve, "Radiation induced noise signals in diagnostic cabling on the Advanced test Accelerator", Proc. Beams '86 Sixth Int. Conf. High-Power Particle Beams, Kobe, Japan, 1986.

Figure 1. Schematic of the optical diagnostic system.

Figure 2. Circuit and timing schematic.

Figure 3. Optical system with dual LOS arrangement and dual detectors.

Figure 4. Example of beam-induced foil optical emission.

Figure 5. Example of beam-induced gas optical emission.

Figure 6. Experimental configuration for a fiber-optic radiation test.

Figure 7. Time-integrated fluorescent signal vs shot number. The beam was tuned to lose more current for the later shots.

Figure 8. Fluorescent signal vs radiation dose (rads).

Figure 9. Fluorescent signal normalized to dose rate plotted as a function of total dosage.

Figure 10. Long-term (three months) irradiation effect on quartz window (Corning 7940) show substantial transmittance loss in the UV region.

Figure 11. Transmission vs wavelength curves before and after irradiation for high-grade quartz (Corning 7940). Radiation dose = 51 krad.