PLANNED OPTICAL DIAGNOSTICS FOR THE APS LOW-ENERGY UNDULATOR TEST LINE

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Abstract

At the Advanced Photon Source (APS), an alternate configuration of the injector linacs (low-energy undulator test line) using an rf gun as the source is projected to provide low, normalized emittance electron beams ($\varepsilon_n \sim 5\pi$ mm mrad). In order to characterize such beams, the present intercepting Chromox screens with limited spatial resolution and temporal response are being complemented by optical transition radiation (OTR) screens at selected positions in the beamline to provide sub-100 μm spatial resolution and sub-ps response times. Both gated cameras and streak cameras will be used to measure the beam properties. Additionally, coherent transition radiation (CTR) and diffraction radiation (DR) based techniques will be evaluated. These beam characterizations will support self-amplified spontaneous emission (SASE) scaling experiments.

1 INTRODUCTION

An increased interest in diffraction-limited light sources for the next generation sources and the implementation of prototype or scaling experiments has been evident since the Fourth Generation Light Source Workshop held in Grenoble in January 1996 [1]. At the Advanced Photon Source (APS), a research and development effort had been underway for several years [2, 3, 4] to use the injector linacs with a low-emittance electron beam source. More specifically, an rf thermionic gun would be used for injection into the 100-to 650-MeV linac subsystem based on the existing 200-MeV electron linac and 450-MeV positron linac. The low, normalized emittance beams ($\varepsilon_n \approx 5\ \pi$ mm mrad) require an upgrade to the existing Chromox viewing screens for characterization of beam transverse size and bunch length. We are in the process of installing optical transition radiation (OTR) screens at selected positions in the beamline to provide sub-100 μm spatial resolution and sub-ps response times [5, 6]. In order to compensate for the reduced brightness of this conversion mechanism, both gated, intensified cameras and streak cameras will be used to measure the beam properties. Initial tests with beam at 650 MeV have been done with a charge-injection device (CID) camera. Additionally, the feasibility of using coherent transition radiation (CTR) and diffraction radiation (DR) based techniques will be evaluated. The diagnostics will be used to characterize, optimize, and monitor the bright beams needed to support self-amplified spontaneous emission (SASE) scaling experiments at $\lambda \sim 120$ nm and a beam energy of 400 MeV as described separately [7].

2 EXPERIMENTAL BACKGROUND

The APS facility's injector system uses a 250-MeV S-band electron linac and in-line S-band 450-MeV positron linac. The electron gun is a conventional thermionic gun in standard operations. For the alternate configuration, an rf thermionic gun, designed to generate low-emittance beams (<5 π mm mrad) and configured with an α-magnet, injects beam just after the first linac accelerating section [4]. Then both in-line linacs can be phased to produce 100-650 MeV electron beams when the positron converter target is retracted.

The rf-gun projected, normalized emittance is orders of magnitude lower than the conventional gun and correspondingly much smaller beam spot sizes ($\sigma_{x,y} \approx 100$ μm) result than from the conventional gun. The standard intercepting screens are based on Chromox of mm-thickness and with a 300-ms decay time [8]. Previous experiences on the Los Alamos linac-driven free-electron laser (FEL) with a low-emittance photoelectric injector (PEI) support the applicability of optical transition radiation screens in this case [9]. A summary of beam properties is given in Table 1. Initial tests of a Ti foil used as an OTR screen at a beam energy of 650 MeV are described in the next section.

Table 1: APS Linac Beam Properties in the Low-emittance Mode (rf Gun)

rf frequency (MHz)	2856
Beam energy (MeV)	100-650
Micropulse charge (pc)	350
Micropulse duration (ps)	3-5 (FWHM)
Macropulse length (ns)	30
Macropulse repetition rate (Hz)	1-20
Normalized emittance (π mm mrad)	~5 (1 σ)

3 BEAM CHARACTERIZATIONS

A general description of the proposed techniques for beam characterization is given in Ref. 2. A subset of those based on optical techniques and now in the installation and testing stage are presented here.

3.1 Transverse Characterizations

Although beam position monitors are also planned using the stripline pickup technology, the transverse beam sizes and profiles are key to evaluating the beam emittance and its preservation throughout the accelerator and transport lines.

At the 50-MeV station, two additional OTR screens are being installed. Although their axial spacing is less than 1 meter, beam quality will be initially checked at this point using the two-screen beam size measurement technique as well as the beam size versus quadrupole-field strength scan technique.

Another key station is at the end of the linac in the transport line, nominally the 650-MeV station. At this point an optical transport line is being installed to bring the OTR light to an optical table outside of the linac tunnel. This table will provide an experimental base for measurements with a gated, intensified charge-coupled device (ICCD) camera (Stanford Computer Optics, Quik-05A). With the microchannel plate (MCP)-based shutter, 5-ns-wide samples from the beam macropulse are possible. The gain factor of the MCP also allows for imaging of defocused spots during a quadrupole field scan for an emittance measurement. The tests of these cameras have already been done on the APS positron accumulator ring (PAR) and the booster synchrotron using synchrotron radiation from ~1 nC charge passing through a dipole.

An initial test of OTR source strength has been done using 1-3 nC of beam in a macropulse from the conventional gun and at energies of 580 and 650 MeV. Since the Ti foil was placed over only the lower half of the Chromox screen at this station, the e-beam could be steered and focused on the Chromox first, and then steered downward to the OTR foil. Figure 1 shows a sample beam image, and Fig. 2 shows the horizontal and vertical profiles with Gaussian fits. Focused spots (~2 mm, FWHM) were readily imaged with the CIDTEC CID camera operating in the X2 gain position with 3 nC in a macropulse. However, normal transport conditions usually have a large spot size at this location and are seen much more readily with the Chromox screen. This baseline measurement supports the OTR screen choice.

The PAR bypass transport line provides a unique opportunity with its 10-m drift space to perform a three-screen emittance measurement. As shown in Fig. 3, the center screen is 5 m from the two end ones. Relay optics will bring the images to a lead-shielded ICCD camera. A fourth screen will be used for OTR interferometer experiments in conjunction with the center screen.

3.2 Longitudinal Characterizations

Since longitudinal beam brightness is related to evaluations of SASE gain, the measurement of bunch duration and profile are also critical in this program.

At the 50-MeV station, one of the OTR screens and one part of the beamline cross will be configured to send the far-infrared (FIR) coherent transition radiation that will be generated by the few-ps or mm-long bunches to a FIR Michelson interferometer. An optical autocorrelation technique will be evaluated as a bunch duration diagnostic [10].

A baseline technique will be based on a Hamamatsu C5680 dual-sweep streak camera viewing the incoherent OTR signal from the 650-MeV station. The transport of OTR to the optics table outside the tunnel will facilitate these experiments. The most likely vertical sweep plug-in will be a synchroscan unit phase-locked to 119.0 MHz, the 24th subharmonic of the 2856 MHz frequency. Low-jitter of the synchronous sum of beam bunches will be advantageous in dealing with the very low charge in a single micropulse. Because the S-band micropulse spacing is much smaller than the 119.0-MHz period, the sequence of micropulses will best be displayed using the dual-sweep technique. This particular 119.0-MHz unit has been successfully phase-locked to an rf source at the Duke Storage Ring FEL facility which is injected by an S-band linac [11]. At APS, a low jitter countdown circuit has been built

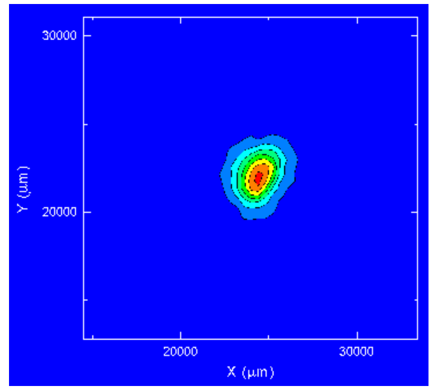

Figure 1: One of the first OTR images of APS linac beam at 650 MeV and ~3 nC in a macropulse from the conventional thermionic gun. A two-frame average was used to improve the statistics.

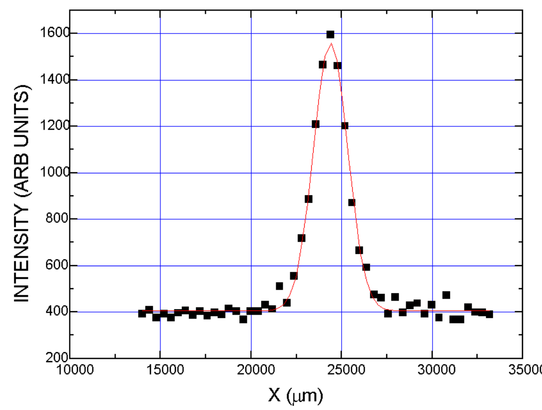

Figure 2: Horizontal profile for the OTR image in Fig. 1. The solid line is a Gaussian profile fit to the data. The beam sizes are about 1 mm (1σ).

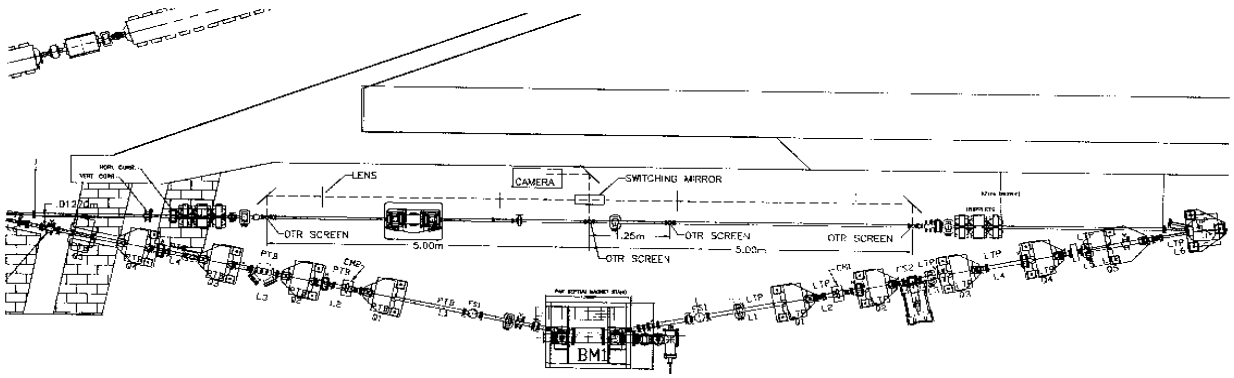

Figure 3: Schematic drawing of the three-screen emittance measuring station at the bypass area to the positron accumulator ring. The 10-m drift space with $B_{x,y}$ ~5 m will allow reasonable rotation of the phase space. A beam waist will be produced on the center screen location.

using Motorola ECLIN PS logic to generate the 24th subharmonics. It has been tested with a 0.7 ps (rms) jitter pulse generator, and the total jitter was observed to be 1.1 ps. Bandpass filters on the output result in a clean 119.0-MHz sine wave to be used with the synchroscan unit [12].

In the two cases above, an intercepting OTR foil is used. For nonintercepting bunch-length measurements, coherent DR is a possible way to extend the Michelson interferometer technique to a nonintercepting category [13, 14]. In the streak camera case, a bend in the transport line, a special few-period diagnostics wiggler, or the final prototype wiggler for the SASE experiments are possible nonintercepting sources of optical radiation for a bunch-length measurement.

4 SUMMARY

In summary, the adjustments of optical diagnostic techniques to low-emittance beams are well underway in the APS linac. Tests of some techniques have already been done with alternative particle beam sources, e.g., OTR, gated cameras, and the synchroscan (119.0 MHz) streak camera. Further tests will be done with the conventional injector, and the initial tests with rf-gun injected beam are expected in the coming months of 1997.

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6 REFERENCES

[1] Proceedings of the Workshop on Fourth Generation Light Sources, Grenoble, France, January 22-25, 1996, J. Laclare (Ed.)

[2] A. H. Lumpkin, S. Milton, and M. Borland, "Proposed Particle-Beam Characterizations for the APS Undulator Test Line," *Nucl. Instr. and Methods* A341, pp. 417-421 (1994).

[3] A. H. Lumpkin et al., "Diagnostics for the APS Undulator Test Line," Proc. of the Fifth Beam Instrumentation Workshop, Santa Fe, NM, Oct. 20-23, 1993, *AIP Conf. Proc.* 319, pp. 211-219 (1994).

[4] M. Borland, "An Improved Thermionic Microwave Gun and Emittance Preserving Transport Line," Proc. 1993 Particle Accel. Conference, Washington, DC, May 17-20, 1993.

[5] D. W. Rule, R. B. Fiorito, A. H. Lumpkin, R. B. Feldman, and B. E. Carlsten, *Nucl. Instr. and Methods* A296, p. 739 (1990).

[6] A. H. Lumpkin, R. B. Fiorito, D. W. Rule, D. Dowell, W. C. Sellyey, and A. R. Lowrey, *Nucl. Inst. and Methods* A296, p. 150 (1990).

[7] S. V. Milton et al., "The Advanced Photon Source Low-Energy Undulator Test Line," these proceedings.

[8] M. White and A. Lumpkin, private communication, Feb. 15, 1997.

[9] Alex H. Lumpkin, "Advanced, Time-Resolved Imaging Techniques for Electron Beam Characterization," Proc. of the 1990 Workshop Accelerator Instrumentation, Batavia, IL, Oct. 1-4, 1990, AIP No. 229, p. 151, and references therein (1991).

[10] H. C. Lihn et al., *Phys Rev.* E 53(b), p. 6413 (1996).

[11] A. H. Lumpkin et al., "Initial Application of a Dual-Sweep Streak Camera to the Duke Storage Ring OK-4 Source," these proceedings.

[12] R. Laird and F. Lenkszus, Argonne National Laboratory, private communication, April 1997.

[13] W. Barry, "Measurements of the Sub-picosecond Bunch Profiles Using Coherent Transition Radiation," Proc. 1996 Beam Inst. Workshop, Argonne, IL, May 6-9, 1996, AIP Conf. Proc. 390, p. 173 (1997).

[14] Y. Shibata et al., *Phys Rev.* E 52, p. 6787 (1995).