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DIAGNOSTICS FOR THE APS UNDULATOR TEST LINE*OSTI

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ABSTRACT

One of the research and development thrusts at the Advanced Photon Source (APS) is to use an rf gun as a low-emittance electron source for injection into the 100- to 650-MeV linac subsystem and subsequent transport to an undulator test area. This configuration would combine the acceleration capability of the 200-MeV S-band electron linac and the in-line 450-MeV positron linac that normally provide positrons to the positron accumulator ring (PAR). A transport line that bypasses the PAR will bring the electrons to the undulator test area. Characterization techniques will be discussed for the electron beam with a normalized, rms emittance of $<10 \pi$ mm mrad (1σ) at micropulse charges of up to 350 pC and micropulse durations of ~ 5 ps (FWHM). Preservation of such beam properties will be critical. The diagnostics planned, with resolutions in parentheses, include the beam position monitors based on stripline pickups (100 μ m), current monitors based on a transformer (60 μ A), beam profile monitors (25 μ m FWHM), and bunch length monitor based on a streak camera (2 ps). Tests proposed include measurement of particle beam transport effects (at one-tenth the storage ring beam rigidity) caused by small undulator field errors.

INTRODUCTION

At the Advanced Photon Source (APS)¹, one of the research and development efforts underway is to use an rf gun² as a low-emittance electron source for injection into the 100- to 650-MeV linac subsystem and subsequent transport to an undulator test area. This configuration would combine the acceleration capability of the 200-MeV S-band electron linac and the in-line 450-MeV positron linac that normally provide positrons to the positron accumulator ring (PAR). A transport line that bypasses the PAR will bring the electrons to the undulator test area. Characterization and preservation of the low-emittance beam will be critical to the undulator tests. At the high energy end of the system, emittance measurements will be done using a three-screen technique over a 10-m drift space as the baseline method with optical

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transition radiation interferometry (OTRI)^{3,4} and variable quadrupole field, single-screen techniques as complementary measurements. To measure the anticipated sub-100- μm spot sizes, OTR conversion screens will be used as well as gated, intensified camera technology⁵. At the low-energy end, due to beamline space limitations, probably the variable quadrupole techniques will be used.

A primary use of the beamline will be to test the effects of undulator errors on particle-beam trajectories at one tenth the beam rigidity of the storage ring beam. There are two other secondary uses of the line. Production of useful quantities of diffraction-limited short wavelength radiation ($<200\text{ nm}$), and possibly even coherent radiation, for use by experimenters will be possible. A further use will be as a test bed to characterize present diagnostics as well as new concepts before installation into the storage ring.

These objectives require preservation of the emittance during acceleration and transport. Simulations predict that a beam of normalized, rms emittance $<2\pi\text{ mm mrad}$ (1σ) at micropulse charges of up to 350 pC can be produced at the gun exit. Compression of bunches to durations of $\sim 5\text{ ps}$ (FWHM) is also predicted, and the emittance objective at the undulator test area is $<10\pi\text{ mm mrad}$.

SYSTEM BACKGROUND

The APS will be a third-generation synchrotron radiation user facility based on a 7-GeV positron beam in an 1104-m circumference ring. The source of these positrons is a thermionic electron gun, two in-line S-band linear accelerators (the 200-MeV electron linac and the 450-MeV positron linac), and the converter target between them. For the low-emittance mode, it is planned to install an rf thermionic gun with an alpha-magnet and inject beam into the electron linac just after the first accelerator tank. The converter target is retracted and the positron accelerator is merely rephased to accelerate electrons. A schematic of this is shown in Fig. 1. As described below, the immediate acceleration of the electrons by the high gradient field makes this a low-emittance source.

The rf gun is a modification of the one operating on the injector at SSRL and was described in detail by Borland in Ref. 2. It is a side-coupled $\pi/2$ -mode, standing-wave structure, and resonant at 2856 MHz. Several changes were made in the APS design to improve beam emittance by a factor of three to four over that of the SSRL gun. The projected normalized emittances of $<10\pi\text{ mm mrad}$ at micropulse charges up to 350 pC at 650 MeV are indicated in Table I. The macropulse bunch length is limited by the rf system. Results of simulations of the gun performance are given in Ref. 2. The emittance expected up to 350 pC per bunch as a function of gun cell field gradient is shown. The highest gradients are advantageous, and at the gun exit emittances less than $2\pi\text{ mm mrad}$ are simulated.

CHARACTERIZATION TECHNIQUES AND SIMULATIONS

A more complete summary of the beam parameters and the diagnostics techniques proposed for characterizing the beam are given in Table II. The nominal value, the span, diagnostic technique system resolution, and measurement

Fig. 1 Schematic of the undulator test line showing the rf gun, in-line linacs, transport line, and undulator test area. In the low emittance mode, the second linac is rephased to accelerate electrons.

Fig. 2 Schematic of the two-foil OTR interferometer technique for measuring particle-beam divergence. At high γ , the large interfoil spacing will allow direct viewing of the interference pattern formed at the front surface of the second foil.

Table I
APS linac beam properties in low-emittance mode (rf-gun)

RF frequency (MHz)	2856
Beam energy (MeV)	100 to 650
Micropulse charge (pC)	350
Micropulse duration (ps)	5 (FWHM)
Macropulse length (μ s)	1 or 5
Macropulse repetition rate (Hz)	1 to 20
Normalized emittance (π mm mrad)	<10 (1σ)

UNDULATOR TEST LINE
TABLE II. PARTICLE BEAM PARAMETERS AND DIAGNOSTICS PERFORMANCE

Parameter	Nominal Value	Span	Technique	Resolution	Error	Bandwidth/ Timescale
Position	Reference line	± 2 cm	BPM, log-ratio OTR foil	100 μ m 25 μ m	250 μ m 25 μ m	2 Hz 30 Hz image
Transverse Profile	$\sigma = 100$ μ m	0.05 to 2 mm	OTR foil	~ 25 μ m(FWHM)	25 μ m	30 Hz image
Divergence	$\sigma = 20$ μ rad	10 to 100 μ rad	OTR, OTRI	~ 10 μ rad	20%	TBD
Emittance	$\sigma_N = 2$ π mm-mrad	2 to 40 π	Three-screen, OTR, OTRI	$\sim 1/2$ π mm-mrad	30%	TBD
Charge	350 pC/bunch	50 to 350 pC	FCT	2 pC	1%	30 ns (macropulse)
Peak Current		1.7 to 12 mA	FCT	60 μ A	1%	
Energy	650 MeV	100 to 650	Bending magnet + detector	0.3%	0.3%	5 Hz
Spread	0.1%					
Jitter	TBD					
Slew	TBD					
Micropulse Duration	5 ps	0.8 to 15 ps	Streak camera, OTR, SR	2 ps	10%	30 Hz image/ 2 Hz calc.
Photon Beam	5 ps	0.8 to 15 ps	Streak camera, OTR, SR	2 ps	10%	30 Hz image
Jitter			Synchroscan			
Slew						
Beam Loss	Relative loss rate and location	Ampl.: 0 to 100% Position: 60 m	Gas-filled coaxial cable Pulse timing	Ampl.: 2×10^{-10} C/s Position: 60 m Ampl.: 0.5 nC Position: <3 m	N/A 60 m N/A <3 m	100 ms 100 ms 100 ms 100 ms

bandwidth/timescale are shown. The discussion below will emphasize the characterization of transverse and longitudinal aspects.

A. Beam Position Monitors

The beam position monitors will be based on stripline pickup technology and a logarithmic amplifier electronics system. The baseline electronics were developed for the S-band linac injector at APS and are described elsewhere by R. Fuja⁶. A portion of the rf board was developed at Los Alamos. The beamline bore is slightly larger in the transport lines after the linac. Estimated position resolution is 100 μm . In the undulator area, higher position resolution is needed so an alternative electronics package will be eventually developed for few- μm resolution.

B. Beam Current Monitors

The beam current monitor is based on the Bergoz fast current transformer as the sensor and uses our APS-developed electronics package with an ultrafast, gated integrator technology. The performance characteristics of the electronics and initial test data were reported by Wang⁷ at last year's workshop. A portion of the circuit is under patent review at this time. The S-band bunch structure will not be resolved, but the macropulse length in the ns to μs regime will be directly measured.

C. Beam Profile and Emittance Measurements

The low-emittance beam at high energies will result in smaller transverse spot sizes than phosphors can typically address so optical transition radiation screens will be used. These will also form the basis of the emittance measurement. The transverse emittance measurements will be done using a three-screen technique over a 10-m drift space (the PAR bypass line of Fig. 1) as the baseline method with optical transition radiation interferometry (OTRI) and variable quadrupole field, single-screen techniques as complementary measurements. To assess the spatial profiles with rms sizes $\sigma_{x,y} \sim 100 \mu\text{m}$, OTR single conversion foils/screens will be used at the three axial locations. Since single micropulse charges are of the order of 350 pC, gated, intensified camera technology will be employed as a complement to standard cameras. The surface-emission character of OTR would avoid the spatial-resolution-limiting effects of phosphor grain size, phosphor thickness, or Cherenkov radiation converter thickness. The OTRI technique is schematically shown in Fig. 2. The forward radiation generated by the beam at the first foil interferes with the backward radiation of the second foil. The angular distribution pattern observed at the backsurface of the second foil exhibits an interference pattern which can be analyzed for beam divergence and energy effects.

Two quadrupoles upstream of the 10-m drift space will allow some adjustment of the partition between beam size and beam divergence when the waist is at the center screen. By matching the spot sizes at the first and third screens with a beam minimum at the center screen, the three-screen formalism to calculate emittance is simplified. Emittance determination with 15 to 20% accuracy with an imaging system

resolution of 25 μm (FWHM) is expected. It is noted that one is observing the projections on the x and y axes, but with 3-location data, one could employ some tomographical techniques for reconstruction of transverse phase space.

For the OTRI, one of the critical aspects is keeping the beam scattering produced by the first foil less than the actual rms divergence of the beam. Preliminary estimates of the scattering for a 650-MeV electron by a 1- μm -thick Al foil are encouraging. Particle beam rms divergences of 20 to 100 μrad should be measurable. A closer look at this for energies between 200 and 650 MeV is planned. Assuming an interfoil spacing of about 125 cm (desired spacing scales roughly as $\gamma^2\lambda$), radiation at 630-670 nm, and an energy of 650 MeV, Fig. 3 shows calculations of interference patterns for 25- to 100- μrad rms divergence. The difference in fringe visibility would be used to determine beam divergence with 10 to 15% accuracy. The calculations were done on a Sun workstation using D. W. Rule's code GINTRF1⁸. Energy centroid effects were also discernable in the calculations, and these are shown in Fig. 4. The two inner peaks directly track the increase in energy with increase in relative intensity. The possibility of using OTR spectroscopy to measure these low emittance beams is under consideration. A simulation of a similar transverse phase space at $E = 185$ MeV was previously addressed for the NIST microtron by Rule and Fiorito⁹.

D. Micropulse Bunch Length

At 350 pC per bunch, the nominal bunch length would be 5 ps (FWHM). This peak current can be increased by bunching, but emittance degradation is possible. Thus, tracking the emittance with peak current is an objective. In particular, producing useful quantities of diffraction-limited radiation is strongly dependent on low emittance, and if one hopes to obtain any coherent radiation, then peak charge density is also critical. In the 10-m drift space area, the micropulse bunch length can be determined via the prompt OTR radiation. Although a fast, single-sweep streak camera measurement is possible, the signal-to-noise ratio in the measurement can be improved using synchroscan techniques at 119 MHz (a subharmonic of 2856 MHz). Resolution of about 2 ps (FWHM) should be possible. This system also could be used to minimize the transverse wakefield effects due to beam center offsets in the accelerator tanks as demonstrated previously.

SUMMARY

In summary, the projected performance of the APS linac operating in the low-emittance mode would extend the demonstrated diagnostic measurement envelope and provide useful data to the community interested in bright sources of radiation. Both the projected generation of diffraction-limited (and possibly coherent radiation at $\lambda < 200$ nm) and the effects of magnetic field errors on the beams and radiation properties are accessible. This information is particularly relevant to designs of the next generation of light sources.¹⁰

Fig. 3 Calculation of the optical transition radiation interferometer pattern at 650 MeV with an interfoil spacing of 125 cm and using a 650 x 40 nm bandpass filter. The values of σ_x for 25, 50, 80, and 100 μ rad are indicated with the lower beam divergences giving the higher fringe visibility.

Fig. 4 Calculation of the optical transition radiation interferometer pattern at energies from 640 to 660 MeV in 5-MeV steps. The two inner-peak intensities go directly with beam energy.

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