BEAM CHARACTERIZATION AND COHERENT OPTICAL TRANSITION RADIATION STUDIES AT THE ADVANCED PHOTON SOURCE LINAC*

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Abstract

The Advanced Photon Source facility includes a 450-MeV S-band linac with the option for injection from a photocathode (PC) rf gun. A diode-pumped, twice-frequency doubled Nd:glass regen laser (263 nm) is used with the Cu PC to generate the electron beams. Characterization of these beams and studies of the microbunching instability following beam compression in the four-dipole magnetic chicane are described. A suite of diagnostics is employed including a three-screen emittance section, a FIR coherent transition radiation autocorrelator, electron spectrometers, and an optical diagnostics end station. Mitigation techniques of the COTR in the beam profile diagnostics are demonstrated both spectrally and temporally. At 100 pC without compression, normalized transverse emittances of 1.8 and 2.7 microns are observed in the x and y planes, in reasonable agreement with initial ASTRA simulations.

INTRODUCTION

At end of CY 2010, the APS photocathode gun (PCG) drive laser was upgraded. Specifically, two flashlamp pumped heads were removed from the Nd:Glass laser regenerative amplifier and replaced with diode-pump heads. The improved laser stability led to a new effort to characterize the linac with and without bunch compression (BC) and examine the generation of coherent optical transition radiation (COTR). An energy chirp impressed on the beam is used to compress the 1-2 ps, rms bunch as it passes through the chicane. With compression, bunch lengths of 170-200 fs, rms at 450 pC are measured, and coherent optical transition radiation (COTR) due to the microbunching instability is observed.

LINAC BEAM CHARACTERIZATION

As shown in earlier measurements [1], the appearance of COTR is strongly dependent on the phase of the linac structure employed to chirp the beam. The linac structures have been described previously, in the same references. During normal operation, one of two thermionic guns provides the electron beam; in this case, the four L2 S-band (2856 MHz) accelerating structures (AS) increase the beam energy from 3 MeV to 150 MeV prior to reaching the L3 four-magnet-chicane, BC section [2]. When using the PCG, an additional AS (L1) is available, which takes PCG output from 5 MeV to 30 MeV. For BC, the L2 AS power is adjusted to again provide 150 MeV at the L3 chicane. The desired BC is achieved by adjusting the L2 phase to negative angles with respect to the on-crest condition and then raising the L2 power by the amount required to maintain 150 MeV at the chicane. During our studies, we found maximum compression at -22°; earlier studies found this angle to be closer to -16°.

Bunch Length

Two types of bunch length measurements were made; first, with an FIR coherent transition radiation (CTR), Golay cell detector in the three-screen emittance section, and second, using a zero-phase technique at the high energy end of the linac. Incoherent and COTR signals are observed on OTR and Ce-doped YAG and LSO scintillation crystals. Near maximum compression, strong flashing is observed from these diagnostics, as shown in Figure 1 on separate study days. The beam is unstable near maximum compression, so we back off somewhat on the L2 phase prior to performing a CTR autocorrelation scan.

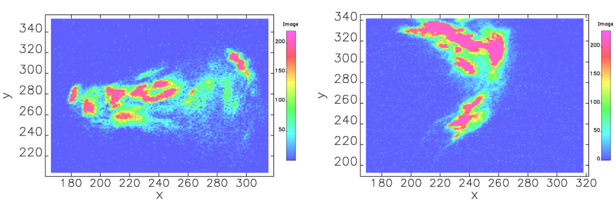

Figure 1: Station 5 OTR screen images acquired during strong COTR. Full-scale horizontal dimension is 3.7 mm; full-scale vertical dimension is 4.5 mm.

CTR autocorrelator scans are presented in Figure 2. For the case shown Fig. 2(a), we have backed off in phase by -5° from maximum compression and only modestly compressed the bunch. For the second measurement (Fig. 2(b)), we were able to get close to maximum compression phase. The central peak represents the autocorrelation result from the interferometer, and the rms pulse widths for these two CTR scans are 401 fs and 173 fs, respectively.

The CTR Golay signal is too low when the bunch is uncompressed. In this case, we employed a zero-phase rf technique that measures longitudinal bunch size at the peak and trough of the rf phase. Here we vary the phase of the L4 and L5 structures to perform the measurement. Bunch length results for uncompressed (1.5 ps, rms) and compressed beam (0.3 ps, rms) are presented in Figure 3(a) and 3(b), respectively.

* Work supported by the U.S. Department of Energy, Office of Science, under contract number DE-AC02-06CH11357.
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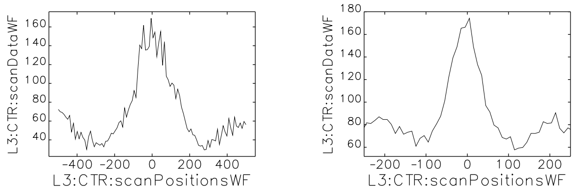
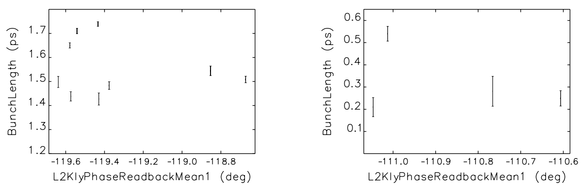


(a) (b)

Figure 2: CTR autocorrelation measurements of compressed beam; (a), L2 phase angle=-17°, (b) = -22°. Note the difference in horizontal scale for the two scans.



(a) (b)

Figure 3: Zero-phase bunch length measurements; (a), uncompressed and (b), compressed.

We also employ ASTRA [3] to examine the compressed bunch length; the FWHM of the longitudinal distribution shown in Figure 4 is approximately 300 fs, in good agreement with measurements.

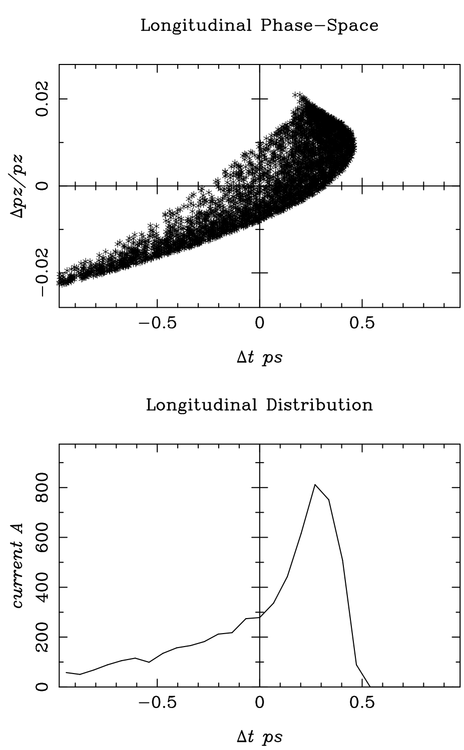


Figure 4: ASTRA (top) longitudinal distribution and (bottom) bunch length projection .

Emittance

Setting the bunch charge at 70 pC, emittance was measured to compare with previous results [4]. A three-screen emittance station is located in the drift space downstream of the chicane and a set of four matching quadrupole magnets. The linac lattice is designed to produce a beam waist at the center flag of the three-screen station. Normalized emittance as a function of PCG solenoid current and bunch charge are presented in Figure 5. Also shown with these data are the predictions from ASTRA simulations. Whereas the data and simulations show emittances to be at a minimum near I_{sol}=115 A, Ref. [4] indicated a significantly higher solenoid current closer to 140 A for measured emittance minima.

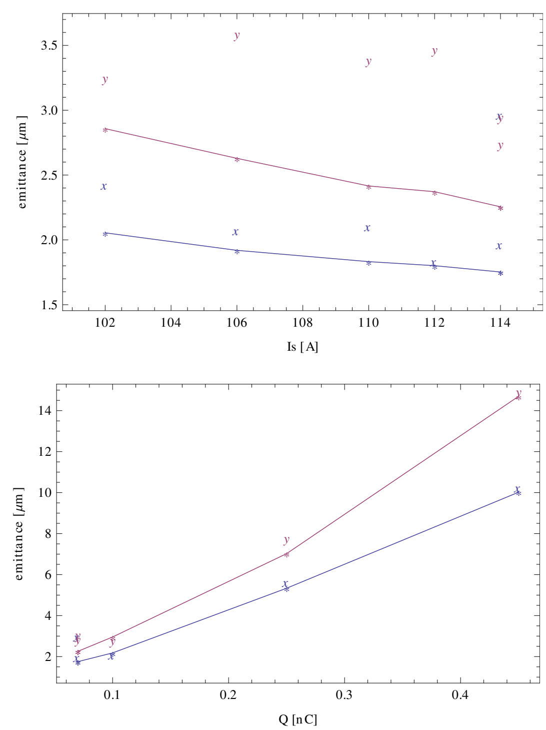


Figure 5: Normalized emittance measurements and ASTRA simulations. Top: ϵ_n vs. I_{sol} and bottom: ϵ_n vs. bunch charge. x,y symbols refer to measurements; * and lines to ASTRA.

COTR DIAGNOSTIC MITIGATION

Station 5 at the high-energy end of the linac includes an optical transport line that brings the beam-generated emissions of OTR screens or scintillators out to a small optics lab where three cameras and a spectrometer were installed. Bandpass filters (BPF) and neutral density (ND) filters were implemented manually in the optical path, as needed. We used a standard VICON CCD camera, a SCO QUIK-05A gated intensified camera, and a Pulnix MCP-Intensified CCD (GaAs PC in the MCP with an enhanced NIR quantum efficiency). We wanted to investigate our options for mitigating the COTR effects in the diagnostics by using spectral filtering, camera sensitivity, and timing aspects.

Spectral

An example of spectral diagnostic COTR suppression is presented in Figure 6. Emission from the LSO:Ce crystal is centered in the violet at 415 nm. Figure 6(a) shows the transverse distribution from the electron beam striking the 0.5-mm-thick crystal; COTR is evident as well from the vacuum-material interfaces. COTR increases toward the red end of the spectrum; therefore, the insertion of a 10-nm-wide BPF centered at 400 nm blocks the longer wavelength COTR emission. This is demonstrated in Fig. 6(b). The VICON CCD camera is employed for this experiment. To see the COTR intensity being comparable to the scintillator emission means the COTR must be a few hundred times brighter than the incoherent OTR. The distorted Gaussian fit seen in Figure 6(c) is corrected with the introduction of the BPF as shown in Fig. 6(d).

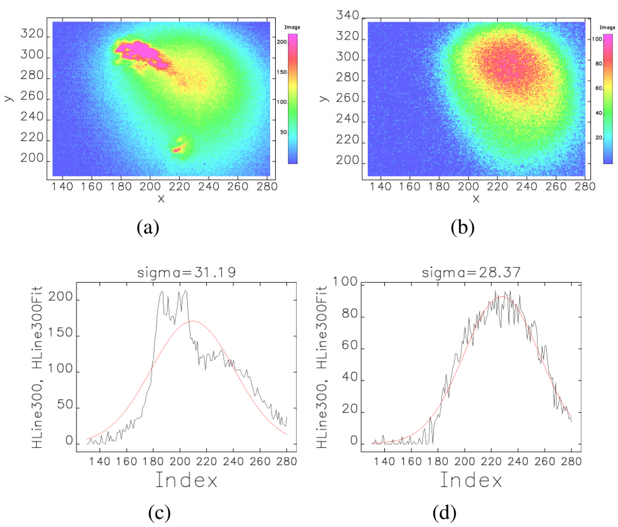


Figure 6: LSO image before and after introduction of a 400 nm x 10 nm BPF. (a) LSO + ND1.0; (b) LSO + 400 nm x 10 nm BPF; (c) H-slice 300; (d) H-slice 300. Full scale horizontal dimension is 3.7 mm; full scale vertical dimension ((a) and (b)) is 4.5 mm.

Temporal

Transition radiation is prompt, whereas scintillation involves emission from excited luminescent centers that can de-excite in tens of nanosecond to milliseconds. In the case of the YAG:Ce and LSO:Ce crystals, the decay time is on the order of 100 ns; therefore, a gated camera can be used to temporally reject light from the prompt COTR [5]. Measured integrated intensities from these crystals as a function of gate delay time are shown in Figure 7 along with exponential fits. Characteristic decay times are 117.5 ns and 73.9 ns for for YAG:Ce and LSO:Ce crystals, respectively. The gated window is 20 ns in duration.

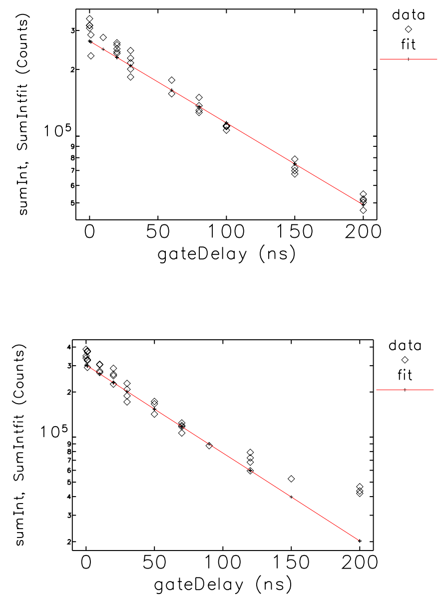


Figure 7: Measured integrated intensity from YAG and LSO crystals versus gate delay time. Top: YAG:Ce, bottom: LSO:Ce; decay times are 117.5 ns and 73.9 ns.

SUMMARY

We have made good progress characterizing the linac using ASTRA. The upgraded laser has performed well allowing us to plan for future experiments. COTR diagnostic mitgation techniques have been demonstrated; however, we must pay careful attention to L2 chirped phase when performing COTR studies.

ACKNOWLEDGMENTS

We wish to thank A. Ting (NRL) for extending the loan of the PC Gun until studies could be completed last summer. C.-x. Wang would like to thank Dr. Flöttmann for his help on using ASTRA. Also thanks to R. Soliday for assistance with data analysis scripts.

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