SPECTRAL AND CHARGE-DEPENDENCE ASPECTS OF ENHANCED OTR SIGNALS FROM A COMPRESSED ELECTRON BEAM*

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Abstract

Strong enhancements of the optical transition radiation (OTR) signal sampled after bunch compression in the Advanced Photon Source (APS) linac chicane have been observed as has been reported in LCLS injector commissioning. A FIR CTR detector and interferometer were used to monitor the bunch compression process of the PC gun beam down to sub-0.5 ps (FWHM) and correlate the appearance of spatially localized spikes of OTR signal (5 to 10 times brighter than adjacent areas) within the beam image footprint. Spectral-dependence measurements of the enhanced OTR were done initially at the 375-MeV station using a series of band pass filters inserted before the CCD camera. Tests with an Oriel spectrometer with CCD and ICCD readout have now been initiated to extend these studies. We also observed that a beam from a thermionic cathode gun with much lower charge per micropulse (but similar total macropulse charge as the PC gun) showed no enhancement of the OTR signal after compression. Reconstructions of the temporal profiles from the autocorrelations of both beams were performed and will be presented. Based on the available spectral and charge-dependent results, the results are consistent with a microbunching instability which results in broadband coherent OTR (COTR) emissions.

INTRODUCTION

The interest in improved understanding of the strong enhancements in optical transition radiation (OTR) from bright linac beams following bunch compression is rapidly growing as evidenced by recent reports in workshops and conferences in the last year [1-4]. The observed features are attributed to a combination of longitudinal space charge (LSC) effects in a linac, coherent synchrotron radiation (CSR) effects, and a Chicane compression process [4]. There appears to be a microbunching instability such that broadband coherent OTR (COTR) is generated in the visible wavelength regime. During the commissioning of the LCLS injector in 2007, such unexpected enhancements of the signals in the visible light OTR monitors occurred after compression in a chicane [1]. Since the Advanced Photon Source (APS) injector complex includes a flexible chicane bunch compressor that is similar to that at LCLS, we have an option to use an rf photocathode (PC) gun, and we had experience with SASE-induced microbunching [5], a series of experiments was performed to explore the phenomena. We initially performed studies on OTR measured at three screens located after the bunch compressor [3]. We used focus-at-the-object or near-field imaging optics and established that there were clear enhancements of the OTR signals at maximum bunch compression. Such enhancements prevent the normal beam-profiling measurements with OTR monitors at LCLS and APS. On the other hand, it has now been suggested that such microbunching structures are favorable to startup of visible-UV light SASE FELs [6].

We also accelerated the compressed beam to the end of the linac and evaluated the enhancements at 375 MeV. The localized spikes in the beam distribution were still visible at this energy. At this latter station we have the light transported outside of the tunnel to a small optics lab that allowed us to perform additional spectral dependency measurements. Moreover, the use of a thermionic cathode gun pulse train with only 40 pC per micropulse did not show the OTR enhancements when the bunch length was compressed comparably to that of the PC gun beam. Discussions of the possible mechanisms will be presented for the APS case which is similar, but not identical to that of LCLS.

EXPERIMENTAL BACKGROUND

The tests were performed at the APS facility which includes an injector complex with two rf thermionic cathode (TC) guns for injecting an S-band linac that typically accelerates the beam to 325 MeV, the particle accumulator ring (PAR), the booster synchrotron that ramps the energy from 0.325 to 7 GeV in 220 ms, a booster-to-storage-ring transport line (BTS), and the 7-GeV storage ring (SR). In addition, there is an rf photocathode (PC) gun that can also be used to inject into the linac as shown schematically in Fig. 1 of reference [3]. An extensive diagnostics suite is available in the chicane and after the chicane area. The tests were performed in the linac at the three imaging stations after the chicane bunch compressor and at the end of the linac where another beam imaging station is located. A FIR coherent transition radiation (CTR) detector (Golay cell) and Michelson interferometer [7] are located between the three-screen emittance stations. A vertical bend dipole and diagnostics screens in this short beamline allow the monitoring of tranverse x-beam size and energy following compression. The YAG:Ce and OTR were directed by

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turning mirrors and relay optics to a Pulnix CCD camera located 0.5 m from the source. These Chicane stations also have options for low- and high-resolution imaging of the beam spot by selecting one of two lens configurations [8]. At the end of the linac, the imaging station (Sta-5) included the optical transport of the visible light out of the tunnel to a small, accessible optics lab where the CCD camera was located. This allowed the access for exploring the spectral dependency of the enhanced OTR. A set of bandpass filters with center wavelengths in 50-nm increments from 400 to 750 nm and 40-nm band width as well as a 500-nm shortpass filter and 500-nm long pass filter were used in the tests. Recently the spectral measurements were extended by adding an optional transport path to an Oriel UV-visible spectrometer with two readout ports. One port used a Vicon 2400 CCD, and the other used an ICCD. The OTR and YAG:Ce images were recorded with a Datacube MV200 video digitizer for both online and offline image analyses, and a video switcher was used to select the camera signal for digitizing. The beam energy was 375 MeV at this station.

INITIAL FIR CTR RESULTS

The experiments were initiated by transporting the PC gun beam accelerated to 150 MeV to the chicane area. The rf phase of the L2 accelerator structure located before the chicane was used to establish the appropriate conditions for compression in the chicane. The degree of compression was tracked with the Golay cell signals. A very strong variation of the FIR signal with L2 phase was observed. There was almost no signal seen when uncompressed and 300 units seen at the peak compression. The autocorrelation scan was then done and showed a profile width of ~65 µm (FWHM) as shown in Fig. 3 of reference [3]. This would mean a roundtrip time of 130 µm, or about 430 fs (FWHM). The initial PC gun drive laser bunch length was 3 to 4 ps (FWHM). The PC gun beam bunch length may be a little longer.

The reconstruction of the time profile was performed by the standard practices as described previously [9]. A bunch length of less than 400 fs [FWHM] with a leading-edge spike was indicated for the PC gun beam. Subsequently the TC gun beam was also compressed and a similar autocorrelation was performed [3]. The zero phasing rf technique was also used to evaluate the compressed bunch length of the PC gun beam and a result of 550 fs rms was obtained. The leading edge spike however has a FWHM of ~440 fs as seen in Fig. 1.

COTR AND OTR SPECTRAL RESULTS WITH PC AND TC RF GUN BEAMS

In order to assess the spectral dependency of the OTR enhancements, we accelerated the beam to 375 MeV and again imaged the beam spot with OTR at a downstream station. As described previously, this station included transport of the signal outside of the tunnel to a small optics lab. First, we still see enhanced localized spikes when we have compressed the beam such as shown in

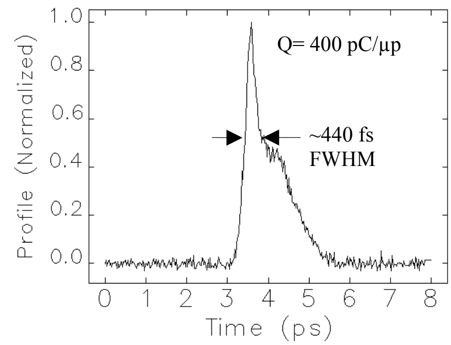

Figure 1: The time profile using the rf zero-phasing mode for the PC rf gun beam with maximum compression.

Fig. 2. We also confirmed that these spikes were present at even a compression level of ½ the CTR signal, although their intensity varied more from shot to shot.

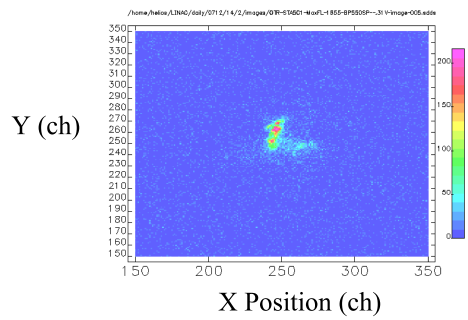

Figure 2: OTR image at 375 MeV showing the enhancements are still present after acceleration beyond the bunch compressor.

At full compression (R_{56} = - 65 mm) we checked the spectral dependency of the enhancements by inserting the bandpass filters in front of the CCD camera. Our preliminary results are that the enhancements were seen at all central wavelengths from 400 to 750 nm (in steps of 50 nm), although relatively weaker in the 400 to 500-nm regime than at 550 nm. We checked the spectral dependence of incoherent OTR from the TC gun beam and saw an intensity rolloff in this short wavelength interval which we attribute to the CCD camera response to these different wavelengths. In Fig. 3 we show the image integrals and peak intensities normalized for CCD response and beam charge. The overall enhancement of the COTR from the PC gun beam is about four times the OTR from the TC gun beam, and the COTR has more red enhancements. This is corroborated by the spectrometer measurements shown in Fig. 4 where the x-localized emission point is shown in both images. It is noted that the YAG:Ce screen is normal to the beam with an Al mirror behind it at 45 degrees. This mirror is in the same plane as the Al OTR screen when it is inserted. The COTR spectral streak profile is more broadband than the YAG:Ce spectrum which is centered near 540 nm as shown in Fig. 5. The spectrometer wavelength span covers ~195 nm from 465 to 660 nm.

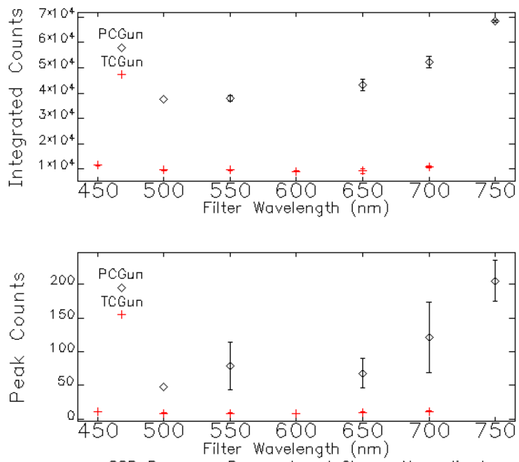

Figure 3: Evaluation of the OTR/COTR image intensities (top) and peak intensities (bottom) versus the bandpass filter center wavelength for the PC rf gun beam (◇) and TC rf gun beam (+). The COTR has a stronger red component than the incoherent OTR.

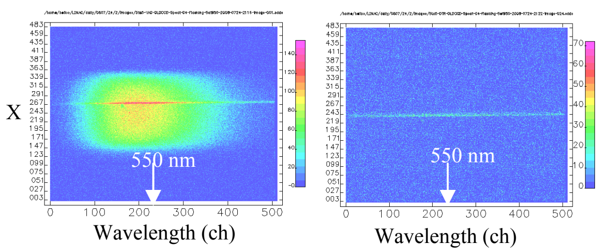

Figure 4: Imaging spectrometer results in x-λ space for YAG:Ce plus an Al mirror (left) and an Al mirror only (right). The localized x extent of the COTR streak in wavelength is evident in both configurations.

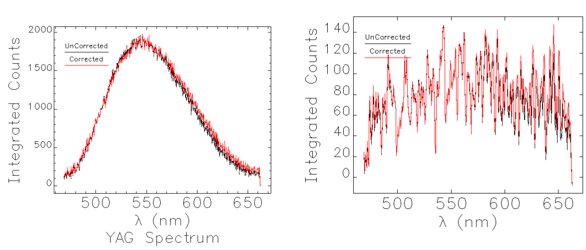

Figure 5: Imaging spectrometer profile results from the images in Fig. 4 for YAG:Ce only (left) and COTR only (right). The COTR spectral streak is more broadband and includes the longer-wavelength red end of the spectrum.

CTR AND OTR RESULTS WITH TC RF GUN BEAM

In the course of our studies, we decided to test the effect with the TC rf gun beam. In this case we could generate about 40-70 pC per micropulse in a macropulse of 25 micropulses that contained about 1-2 nC total. So the integrated incoherent OTR signal should be larger than that of the PC gun beam. With the combination of compression in the alpha magnet of the TC gun system and the chicane, we were able to generate a similar autocorrelation FWHM. However, we observed no enhanced spatial structures or altered spectral content.

SUMMARY

In summary, we have extended our investigations on enhancement of OTR signals in the visible light regime following bunch compression of our PC rf gun beam at APS. We have evidence that the spectral content of the COTR is redder than that of the incoherent OTR. Although the enhancements are not as high as that reported at LCLS, we do see order of magnitude signal increases in localized spatial spikes. At this time the coherent enhancement appears consistent with a fine spike(s) in the longitudinal distribution that develop after bunch compression or broadband microbunching. We did not see the effects in the TC gun beam when compressed similarly, but this involved only 70 pC per micropulse compared to 450 pC for the PC gun. Start-to-end simulations are warranted for the APS case. The growing interest in these COTR effects is indicated by the time allowed for discussion in the planned Microbunching Instabilities Workshop at Berkeley in October 2008 [10].

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