MITIGATION OF COTR DUE TO THE MICROBUNCHING INSTABILITY IN COMPRESSED ELECTRON BEAMS*

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Abstract

We have demonstrated a technique to mitigate the intensity of the coherent OTR (COTR) relative to the OTR signals on the Advanced Photon Source chicane-compressed beams at 325 MeV. Since the reported spectral content of the COTR at LCLS after the first compression stage is similar, the concepts should also apply to LCLS. We utilized the stronger violet content at 400 nm of the OTR compared to the observed gain factors of the COTR in the green to NIR. We also demonstrated the use of an LSO:Ce scintillator that emits violet light to support lower-charge imaging.

INTRODUCTION

The challenge of mitigating the strong enhancements of the optical transition radiation (OTR) signal observed after bunch compression in the Advanced Photon Source (APS) linac chicane and at the Linac Coherent Light Source (LCLS) has been addressed recently. An improved understanding of the strong enhancements in OTR from bright linac beams following bunch compression is occurring 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]. Such enhancements prevent the normal beam-profiling measurements with OTR monitors at LCLS and APS. Since the APS injector complex includes a chicane bunch compressor and we have microbunching interests [5], we decided to study these COTR effects.

Spectral-dependence measurements of the COTR were done initially at the 375-MeV station using a series of band pass filters inserted before the CCD camera, but recent tests with an imaging spectrometer with ICCD readout have extended those studies and confirmed the mitigation concepts. These techniques are complementary to the proposed use of a laser heater to mitigate the microbunching itself at LCLS.

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EXPERIMENTAL BACKGROUND

The measurements 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, the booster synchrotron that ramps the energy from 0.325 to 7 GeV in 220 ms, a booster-to-storage-ring transport line, and the 7-GeV storage ring. 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 [6] are located between the second and third screen of 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 emission and OTR were directed by 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 [7].

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 as shown in Fig. 1. For some of the experiments we installed a GaAs photocathode microchannel-plate-intensified CCD camera, Pulnix model DN007. This device has a strong, flat response from 550 to 880 nm in the NIR. 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 the location of this imaging station.

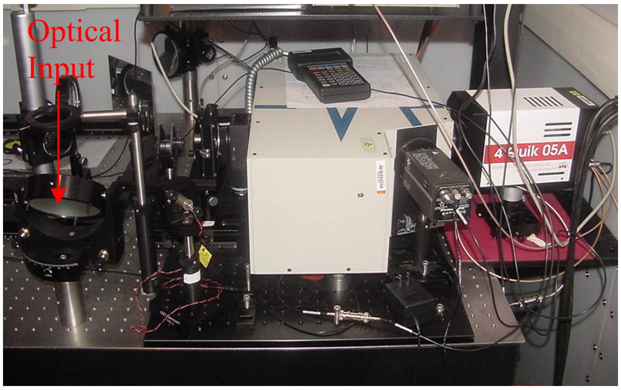

Figure 1: Photograph of the transport optics, Oriel Spectrometer, and two readout cameras for Sta-5.

INITIAL 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 CTR signal correlated 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 performed and showed a profile width of ~65 µm (FWHM) as shown in Fig. 10 of reference [3]. This would mean a path length difference between the mirrors 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 depends on rf gun phasing and charge density.

The reconstruction of the time profile was performed by the standard practices as described previously [8]. 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 [9]. 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 of reference [9].

COTR AND OTR SPECTRAL RESULTS WITH PC RF GUN BEAMS

In order to assess the spectral dependency of the OTR enhancements, we accelerated the beam to 375 MeV and 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 sufficiently. At full compression, 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. 2 we show the image integrals normalized for CCD camera response and beam charge. The overall enhancement of the COTR from

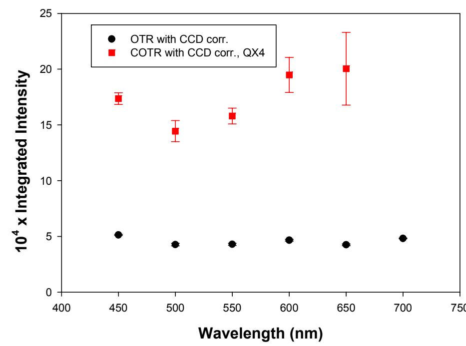

Figure 2: Evaluation of the OTR/COTR image intensities versus the bandpass filter center wavelength for the PC rf gun beam (red) and TC rf gun beam (black). The COTR has a stronger red component than the incoherent OTR.

the PC gun beam is about four times that of the OTR from the TC gun beam, and the COTR has more enhancement in the red end of its spectrum.

This is supported by the imaging spectrometer measurements shown in Fig. 3 where the x-localized emission point is shown in both images. It is noted that the YAG:Ce and LSO:Ce crystals are normal to the beam with an Al mirror behind each 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 530 nm as shown in Fig. 3(left). The spectrometer wavelength span covers ~195 nm from 465 to 660 nm. The central wavelength for the LSO:Ce emission is 415 nm as indicated (right).

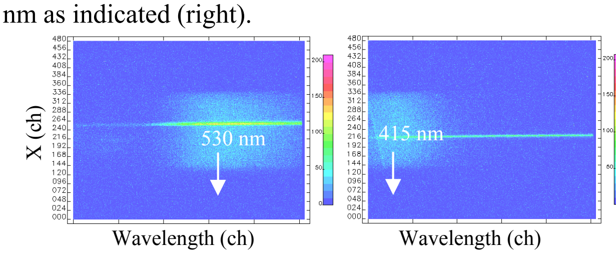

Figure 3: Imaging spectrometer results using the CCD camera readout in x-λ space for YAG:Ce crystal plus an Al mirror (left) and the LSO:Ce crystal plus an Al mirror (right). The localized x extent of the COTR streak in wavelength is evident in both cases.

To explore further the NIR portion of the COTR spectrum, we installed the Pulnix ICCD camera which is based on a GaAs photocathode providing almost flat response from 550 to 880 nm. This complements the CCD camera response which covers down to 380 nm and falls off in sensitivity after 550 nm. The GaAs response does roll off rapidly at each end of this range. However, the data show the very strong increase of the COTR intensity past 650 nm in contrast to the decreasing intensity seen for incoherent OTR in a separate run with TC rf gun beam. This reinforces the concept of the NIR COTR component.

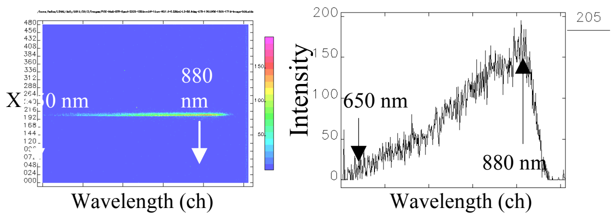

Figure 4: Imaging spectrometer results using the GaAs PC MCP-ICCD in x-λ space for COTR from an Al mirror (left) and the COTR spectral profile (right). The localized x extent of the COTR streak in wavelength is evident.

MITIGATION OF COTR EFFECTS

The mitigation of COTR effects in the beam profiling screens is based on a combination of experimental techniques. The principal issue is to improve the OTR signal to COTR ratio by imaging in the violet to UV end of the spectrum. This is graphically illustrated in Fig. 5 where the relative OTR intensity dependence on $1/\lambda^2$ is shown. We compare this to an example of the OTR multiplied by the COTR gain factor for a 3-keV slice energy spread term as calculated in ref.[10]. It is clear that for this scenario a bandpass filter centered at 400 nm would suppress or mitigate the COTR contributions.

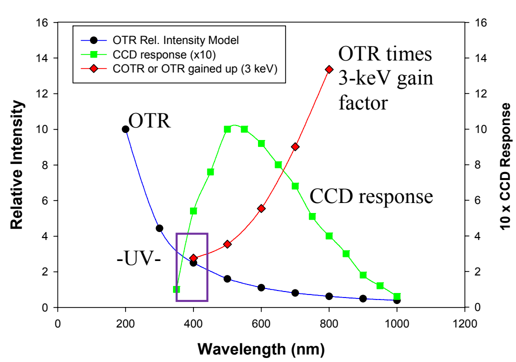

Figure 5: Analytical representations of the OTR dependence on $1/\lambda^2$ and OTR times the 3-keV gain factor, or COTR. The CCD camera response is also shown.

We can also combine the suppression of the COTR with the 400-nm BPF and the response of the LSO:Ce crystal to produce a beam profile image that is not corrupted by COTR spikes as shown in Fig. 6. Additionally, one could use solar blind or UV filters with UV sensing cameras to select 380 to 200 nm OTR with reduced COTR.

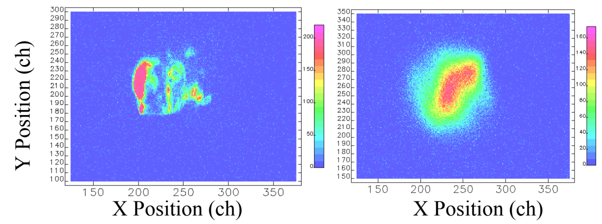

Figure 6: Beam Images via COTR from an Al mirror (left) and the 400-nm bandpass filtered LSO:Ce crystal emissions plus Al mirror COTR (right).

SUMMARY

In summary, we have characterized the COTR spectral content and found that indeed there is a strong red to NIR component. We then demonstrated the mitigation of the COTR spikes by using a violet bandpass filter with the option of an LSO:Ce crystal. We also proposed the use of UV optics and cameras to avoid the COTR even more.

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