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BUNCH LENGTH MEASUREMENTS WITH A STREAK CAMERA IN LOW ALPHA LATTICE OPERATION AT THE TPS

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Abstract

Recently, we developed and tested a lower momentum compaction factor (low alpha) lattice at the Taiwan Photon Source (TPS). Operating in a low alpha lattice can provide picosecond bunch lengths for time-resolved research and generate coherent IR/THz synchrotron light. A bunch length of about 2.5 picosecond rms was measured by a streak camera in low alpha mode while operating in routine users mode it is as long as 10 picosecond [1]. In this paper, we discuss related processes and measurements.

INTRODUCTION

Temporal coherence of radiation depends on the emitting bunch length shorter than the radiation wavelength of interest. Thus, bunch lengths of a few picosecond (ps) or shorter can produce coherent THz/IR light and for X-ray time-resolved experiments. Some 3rd generation synchrotron light sources in the world be able to switch between normal operating mode and a low alpha mode for users operation easily. For examples, the Diamond light source [2] and BESSY II [3] can operate in the "THz" or "low alpha mode" for 3.3 and 3-ps rms bunch lengths, where the first order alpha factor α_1 = -6×10^{-5} and 7.3×10^{-6} at bunch currents of 50 and 30 μA, respectively. In SOLEIL, a bunch length of 4.8-ps for α_1 = 1.7×10^{-5} was achieved a bunch current of 65 μA [4]. From SPEAR3, a 5.9-ps bunch length with $\alpha_0/8.4$ at 86 μA was reported [5]. Some other quasi-isochronous experiments are presently in progress to push the limits of bunch length shortening by operating at a lower momentum compaction factor like NewSUBARU [6], Super-ACO [7], ESRF [8] and ALS [9].

The TPS was commissioned at the end of 2014 and began routine users operation in September 2016. Low alpha lattice studies in the real machine started recently. Bunch length measurements for low alpha lattices with low and high emittance modes in the TPS will be presented here. A streak camera is an adequate instrument used for the bunch lengths measurement with accuracy to few ps. However, for sub-picosecond and fs bunch lengths experiments, it should be evaluated by an optical cross-correlator, e.g. with a non-linear crystal and probe laser [10].

STREAK CAMERA SETUP IN TPS

A photon diagnostics beam line is available for beam size, emittance, filling pattern and bunch length measurements in the TPS [11].

As shown in Figure 1, the visible light was collimated via two pairs of mirrors and a focusing lens and then filtered by a band-pass filter at a center wavelength of 500 nm with a 10 nm bandwidth. A steak camera (Model C10910 series, Hamamatsu Photonics) is used mainly to monitor and observe the bunch length and longitudinal instability in the TPS. For bunch length measurements, the synchro-scan frequency is 250 MHz and the photon sensitivity and quantum efficiency of the streak camera are shown in Figure 2. For reproducible and simple measurements, usage of monochromatic light is preferable to avoid distortion of the signal due to the nonlinear response of the streak camera.

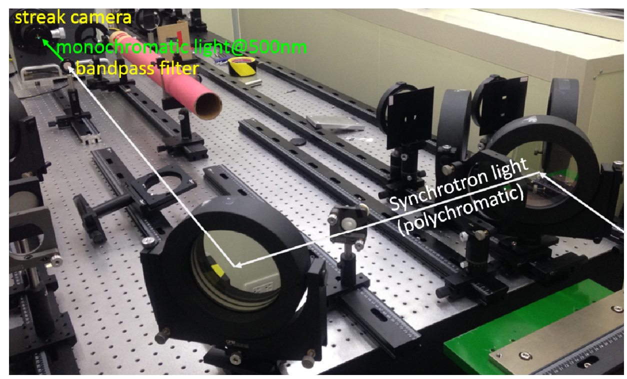

Figure 1: Streak camera setup on the photon diagnostic beam line.

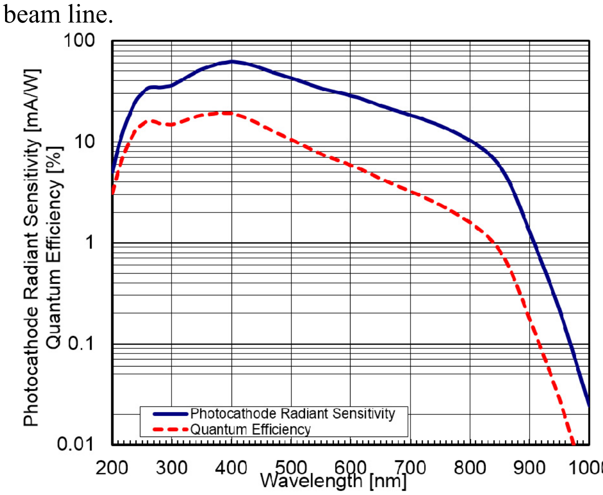

Figure 2: Sensitivity (blue) and quantum efficiency (red) of the photocathode in a streak camera (C10910 series, Hamamatsu Photonics) [12].

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RESPONSE OF STREAK CAMERA TO POLY AND MONOCHROMATIC LIGHT

The synchrotron light passes a pair of lenses before hitting the phosphor screen in the streak camera. The lenses represent a dispersive medium which is characterized by a frequency dependent susceptibility χ(ν), refractive index *n*(ν), electric permittivity ϵ(ν) and reduced light speed in the media $c_0/n(\nu)$, where c_0 is the light velocity in vacuum [13]. A dispersive media can broaden the light pulse because of the velocity dependence on the frequency components that constitute the light pulse.

We compared the relation between the spectral bandwidth of synchrotron light and bunch length measurements of the electron beam. The bunch current is 75 µA within an 850 nsec bunch bucket in normal user operation mode. In front of the streak camera, we inserted two optical band-pass filters with 10 and 25 nm bandwidth, at a center wavelength of 500 nm, for monochromatic light detection. The synchrotron light, whether mono- or polychromatic, was adjusted by a photo diode to keep the same power of 12 nW. Figure 3 shows the spectra of the synchrotron light with and without optical band-pass filters.

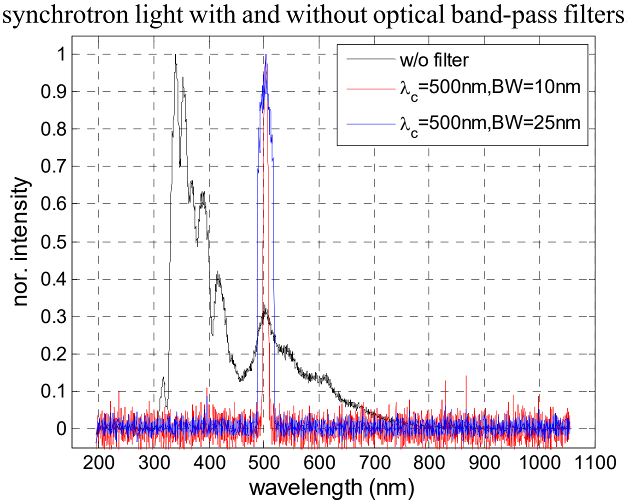

Figure 3: Normalized spectral intensity of synchrotron light without filter (black) and with a 10 nm (red) and 25 nm (blue) FWHM□bandwidth□filter. The measured rms bunch lengths are 13.8, 12.8 and 13 ps for these three setups, respectively. The narrower bandwidth of synchrotron light results in a shorter bunch length due to less dispersion induced by non-linear optical components.

ALPHA VALUES AND BUNCH LENGTH MEASUREMENTS

Operation of the low alpha lattice at TPS [14] could be accomplished by changing the polarity and strength of quadrupole magnets from the normal users operation mode. After optical corrections for the beam orbit [15], the momentum compaction factors were derived by two methods as described below.

1. Synchrotron tune measurement fitting [7] (ν_s vs. Δf_{rf}):

$$\nu_s = \sqrt{\frac{heV_{rf}cos\varphi_s}{2\pi E}}\left(\alpha_1^2 - 4\alpha_2\frac{\Delta f_{rf}}{f_{rf}}\right)^{\frac{1}{4}}, \qquad (1)$$

$$\varphi_s = sin^{-1}\left(\frac{U_0}{V_{rf}}\right)$$

rewriting as $\nu_s^4\left(\frac{2\pi E}{heV_{rf}cos\varphi_s}\right)^2 = \alpha_1^2 - 4\alpha_2\frac{\Delta f_{rf}}{f_{rf}}$

In Eq. (1), ν_s is the synchrotron tune, h the harmonic number, V_{rf} the RF gap voltage, φ_s the synchrotron phase, U_0 the energy loss per turn, E the beam energy, Δf_{rf} the synchrotron frequency shift, f_{rf} the synchrotron frequency and α_1, α_2 are the first and second order momentum compaction (alpha) factors, respectively.

2. Orbit offset from RF frequency change fitting (COD vs. Δf_{rf}):

$$\frac{\Delta f_{rf}}{f_{rf}} - \alpha_1\delta + \alpha_2\delta^2 = 0, \qquad (2)$$
$$\delta = \frac{\sum \Delta x_i D_i}{\sum D_i^2}$$

In Eq. (2), Δx is the orbit offset due to the change in the RF frequency and $D_{x,i}$ the dispersion function at characteristic positions.

Keeping a 30-mA beam current at a 3.2 MV RF gap voltage, we measured the alpha factors in the low emittance, low alpha lattice as listed in Table 1, where case I and II are two different alpha factor lattices with low emittance mode, respectively. Measurements of two cases by synchrotron frequency shifts are shown as Figure 4(a) and (b).

Table 1: Comparison of Alpha Factor Measurements for Low-Alpha Lattices in the TPS

case		model	ν_s v.s. Δf_{rf}	COD v.s. Δf_{rf}
I	α_1	4.2×10^{-5}	4.74×10^{-5}	4.4×10^{-5}
	α_2	-1.9×10^{-3}	8.4×10^{-4}	-1.7×10^{-3}
II	α_1	2.6×10^{-5}	2.84×10^{-5}	3.0×10^{-5}
	α_2	7.15×10^{-4}	6.25×10^{-4}	1.2×10^{-3}

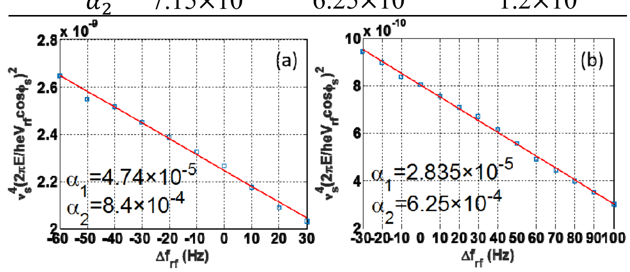

Figure 4: Alpha factors of case I (a) and case II (b) by synchrotron tune shift measurements.

For case II, Figure 5 displays the images from the streak camera with increasing bunch currents in 100 equal bunches at a RF gap voltage of 2.8 MV RF. The rms bunch lengths were also recorded in the multi-bunch mode below threshold of beam instability and then, switching to single-bunch mode, continued to extend the bunch length measurements as shown in the Figure 6 (a) and (b). Furthermore, we attempted to operate lower alpha configurations in high emittance lattices. But very tight injection condition and serious instability led posed serious difficulties in the study. Figure 7 shows the average rms bunch length measurements with one standard deviation error bars.

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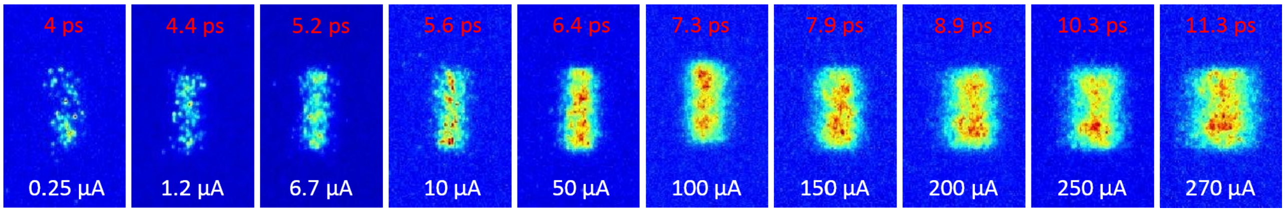

Figure 5: Bunch length projections for increasing bunch currents in the TPS from a streak camera.

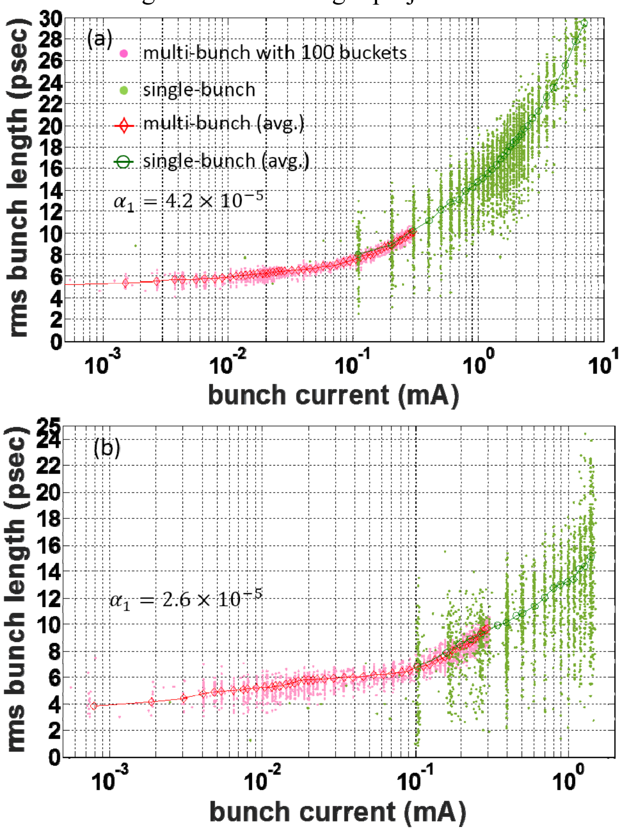

Figure 6: Rms bunch lengths for an increasing bunch current from case I (a) and II (b), where solid dots symbolize measured counts. Red hollow diamonds and green hollow circles indicate operation in multi-bunch and single-bunch mode with average, respectively.

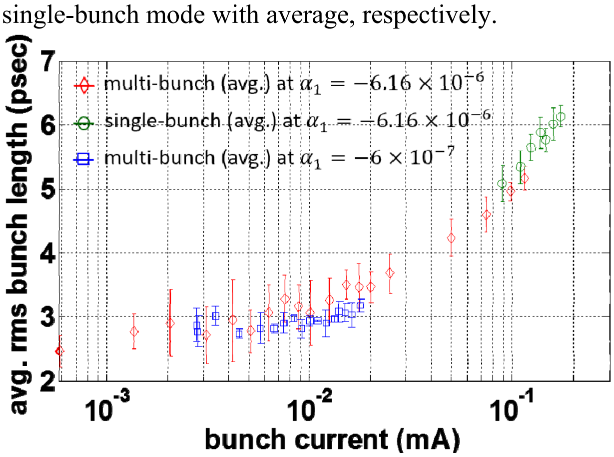

Figure 7: Rms bunch length measurements in low alpha lattices with high emittance mode, where the linear momentum compaction factor is α_1= -6.16×10^{-6} (red and green) and -6×10^{-7} (blue).

CONCLUSION

In this preliminary study on low alpha lattices at the TPS, optical orbit correction, momentum compaction factors and bunch lengths measurements were discussed. Monochromatic light should be used for the streak camera to avoid effects from spectral dispersion in the medium. A 6-ps rms bunch length for a 50 μA bunch current can be confidently produced in low alpha lattices with low emittance mode. This operation promises a high potential for users operation to generate short light pulses from short bunches. In low alpha lattices with high emittance mode, we even observed in the streak camera an extremely short bunch length of 2.5-ps rms at a bunch current of 600-nA.

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