DUAL-SWEEP STREAK CAMERA MEASUREMENTS OF THE APS USER BEAMS*

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Abstract

The diverse user community of the Advanced Photon Source (APS) has now evolved to include those who use the time structure of the APS x-ray beams. The APS normally runs with a 24-singlets fill, a hybrid fill with a singlet and eight septuplets, or a 324-singlet fill pattern. In all cases the total stored beam current is 100 mA, with the lattice providing a natural emittance of about 2.5 nm rad. The first two patterns are used with a top-up mode that involves injection of one pulse of ~2.5 nC every two minutes into the designated storage ring (SR) bucket. Dual-sweep streak camera measurements (Hamamatsu model C5680) have been performed to characterize the individual and average bunch lengths in the fill patterns. The bunch lengths vary from 25 ps (sigma) in the 324-singlets fill to 50 ps (sigma) when the singlet in the hybrid fill has 7.5 mA. Example streak images of each pattern as well as a development mode will be presented and discussed.

INTRODUCTION

The Advanced Photon Source (APS) is a hard x-ray user facility based on a 7-GeV storage ring (SR) [1]. To accommodate the requests of the diverse user community, the APS normally runs with a 24-singlets fill pattern, a hybrid fill with a singlet and eight septuplets, or a 324-singlet fill pattern. In all cases the total stored beam current is 100 mA, with the lattice providing a natural emittance of about 2.5 nm-rad. The first two patterns are used with a top-up mode that involves injection of one pulse of ~2.5 nC every two minutes into the designated SR bucket. Since the partition of bunch current varies for the different fills as well as the loading of the rf cavities, dual-sweep streak camera measurements have been performed to characterize the average and individual bunch lengths in the fill patterns and the phase slew that occurs within the patterns. The bunch lengths vary from 25 ps (sigma) in the 324 singlets pattern to 50 ps when the singlet in the hybrid fill has 7-8 mA. The characterizations have been provided to the growing number of users who use the time structure of the APS x-ray beam.

EXPERIMENTAL BACKGROUND

The APS 7-GeV storage ring operates normally with a 100-mA beam current, electron beam emittance of 2.5 nm rad, and a vertical coupling of 1%. In top-up mode the injector provides a pulse of ~2.5 nC at 2-minute intervals to maintain the beam current within 0.1% of the target 100 mA [2]. The ring has 80 dipoles; about 30 are online for user beamlines. There are 34 straight sections for user insertion devices (IDs) that generate the hard x-rays. The x-ray bunch structure is dictated by the electron beam of course.

An additional sector is dedicated to electron beam diagnostics [3]. The sector layout is shown in Fig. 1. Sector 35 is the only sector that has a front end to transport radiation from the dipole on either side of the diagnostics undulator. From the 35-BM source we have three beamlines. The optical synchrotron radiation (OSR) is picked off by a cooled mirror and transported to the 35-

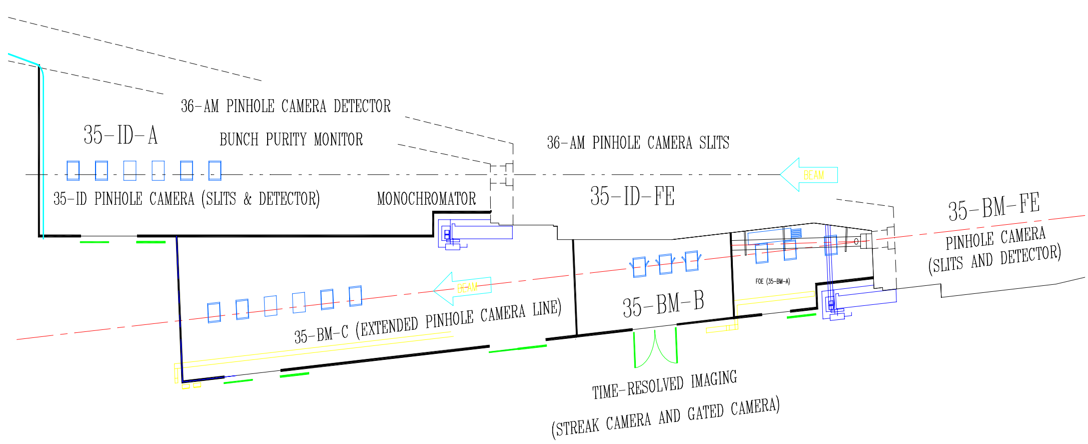

Figure 1: Schematic of the beamlines in Sector 35 dedicated to electron beam diagnostics. The S35 bending magnet (BM) dipole source is used for the OSR detected by the streak camera.

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BM-B experimental station. At this station a standard camera, a gated camera, and a Hamamatsu C5680 dual-sweep streak camera are located. For the vertical sweep unit, we used a model M5675 synchroscan unit tuned at 117.3 MHz, one-third of the 351.9-MHz master rf oscillator frequency. For these experiments we employed the 1-ns range (R3), which has a 2-ps/ch calibration factor. The horizontal sweep unit, model 5679, provided selectable time ranges from 100 ns to 100 ms. We chose the 5-µs range to cover the 3.68-µs single period of the SR. We used 5 ms for the transient test. The streak images were digitized by a DataCube MV200 video digitizer.

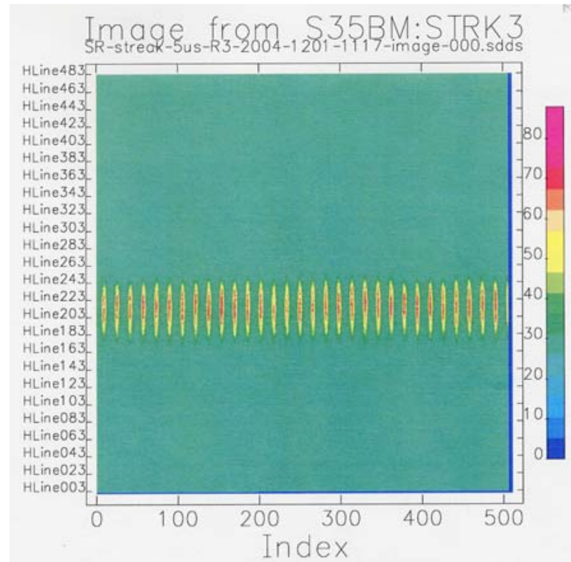
RESULTS AND DISCUSSION

Since the OSR provides a nonintercepting method for measuring the bunch length, we could verify the fill pattern parameters during the actual user run period. Two of the fill patterns were done this way and the third done on a studies day between user runs. Since the zero-current bunch length is about $\sigma_t = 20$ ps for our nominal conditions, we expect each fill pattern to have bunch lengths longer than this value due to potential well distortion (PWD) effects.

The 24-singlets fill is the one used for the majority of the time. This is a uniform spacing fill so the charge is injected every 54 buckets for a spacing of 140 ns and single bunch current of ~4.5 mA. Since this bucket spacing number is divisible by three, we are able to see all 24 singlets using the 117.3-MHz unit operating at the third subharmonic of 351.9 MHz for the synchroscan operations. The dual-sweep streak image with 1-ns range in the vertical axis and 5-µs range in the horizontal axis is shown in Fig. 2. The average over several buckets gives a bunch length of $\sigma_t = 40 \pm 5$ ps. With this streak camera setup we have also recorded the signatures of various HOM instabilities as reported previously [4], where the bunch to bunch phase oscillation is clearly shown.

The hybrid fill pattern includes a singlet at bucket zero and eight septuplets located on the "other side of the ring." This pattern has several characteristic features as shown in Fig. 3. The singlet with 8 mA has the longest bunch length of $\sigma_t = 50$ ps. The other 92 mA are spread across the 56 buckets at about 1.7 mA per bucket. On this display range we see each of the septuplets has a bunch length of $\sigma_t = 32$ ps, but there is a distinct phase slew of about 10 ps from the first to the last. This slew results in an average bunch length of about 40 ps over the 56 buckets. The selectable region-of-interest in processing the image data allows us to isolate the singlet and each septuplet. However, we note that due to the consecutive buckets filled within a septuplet, the synchroscan frequency of 117.3 MHz results in our sampling only bucket numbers 1, 4, and 7 of the septuplets. Recent changes in the SR setup have resulted in up to 12 mA being injected into the singlet, but the lifetime is then so short that top-up would need to occur once per minute. This mode is under consideration for future runs.

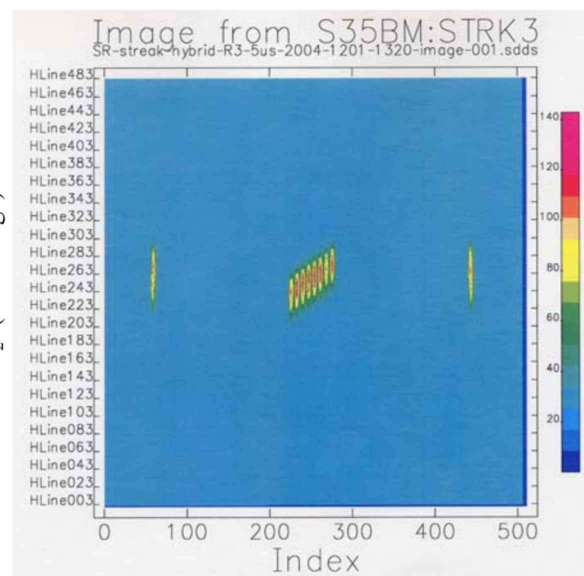
T_2 (1-ns range)



T_1 (5-µs range)

Figure 2: Dual-sweep streak camera image of the 24-singlets fill using a 1-ns vertical range (R3) and a 5-µs horizontal range. All 24 singlets are seen individually in one turn plus a portion of a second turn. The bunch length is 40 ps.

T_2 (1-ns range)



T_1 (5-µs range)

Figure 3: Dual-sweep streak camera image of the hybrid fill using the same ranges as Fig. 2. In this case the singlet is clearly isolated from the eight septuplets. The display does not show the individual members of the septuplets. The singlet has a bunch length of about 50 ps.

The 324-singlets fill pattern results in a 4-bucket, or 11.2-ns, spacing and an average single-bunch current of 0.3 mA. In practice, the bunches are not uniformly filled, and each top-up shot of charge is a noticeable fraction of the total charge in the bucket. In Fig. 4 we show an example dual-sweep streak image with the vertical axis spanning 1 ns and the horizontal axis spanning 5 µs. One revolution of the beam in the ring takes 3.68 µs so we see about 1 ½ turns. The horizontal extent of each bunch is now unresolved on the horizontal axis, and we see a band of light whose vertical height is $\sigma_t = 25 \pm 2$ ps. There are also vertical stripes in the image, which we attribute to the non-uniform fill of the buckets. This interpretation is supported by the independent bunch-by-bunch current monitor, which shows the nominal 0.25-mA-filled buckets and then a few 0.5-mA bunches spaced around the ring. The results on all three fill patterns are summarized in Table 1.

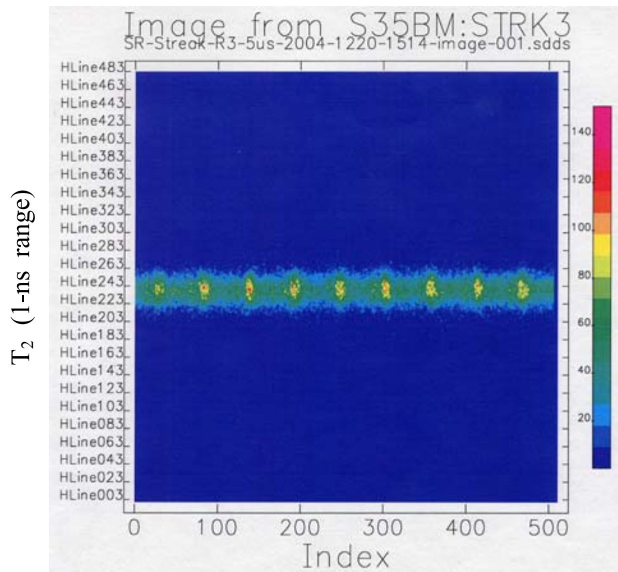


Figure 4: Dual-sweep streak camera image of the 324-singlets fill using the same ranges as Fig. 2. In this case the singlets are only four buckets apart and their spatial extent merges them into a horizontal band of light. The bunch length is 25 ps.

Table 1: Summary of Bunch Lengths in APS for Different Fill Patterns

	24-singlets	Hybrid: 1+8*7	324-singlets
Bunch length	40 ps	Singlet: 50 ps Septuplet: 32 ps	25 ps

More recently, the user interest in shorter bunch lengths than in these three fill patterns has resulted in experiments to provide shorter bunch lengths, but in a transient time manner. The same streak system has been used in such experiments. Both rf phase-modulation and synchro-betatron oscillation techniques have been used [5-7]. In Fig. 5 we show an example of the rf phase modulation technique. The phase modulation is gated on for eight cycles at 4.1 kHz and about 1 ms into the display ramp time. The bunch length oscillations include bunch elongation and compression from the nominal 3-mA value of $\sigma_t = 35$ ps. The shortest bunch is about ½ the normal value at this single-bunch current.

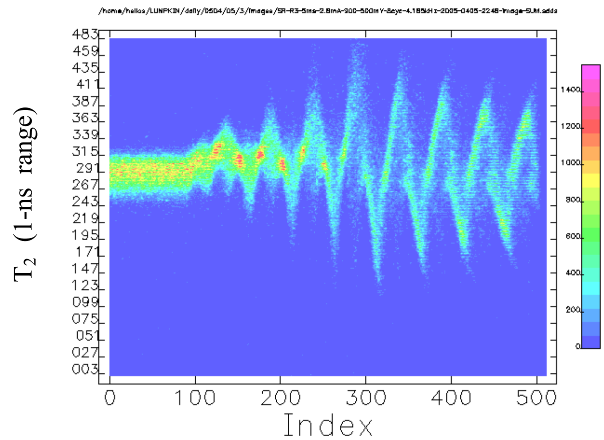


Figure 5: Dual-sweep streak camera image of a singlet fill with only 3 mA using a 1-ns vertical range and a 5-ms horizontal range. In this case the rf phase modulation technique results in a bunch length oscillation with compression of the nominal 35-ps bunch to 18 ps during the minimum of the oscillation.

SUMMARY

In summary, we have characterized the electron-beam and hence x-ray bunch length for the three major APS user fill patterns employed as of December 2004. The bunch spacing, bunch length, and phase have been addressed. We also report results on a transient short bunch mode. These results have been provided to the users for designing their experiments for expected machine performance during the user runs.

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REFERENCES

[1] J.N. Galayda, Proc. of the 1995 Particle Accelerator Conference, 4-8 (1996).
[2] L. Emery, Proc. of the 2001 Particle Accelerator Conference, 2599 (2001).
[3] B. Yang, A.H. Lumpkin, L. Emery, and M. Borland, BIW 2000, AIP Conf. Proc. 546, 622-630 (2000).
[4] A.H. Lumpkin, B.X. Yang, and M. Borland, BIW 2004, AIP Conf. Proc. 732, 366-372 (2004).
[5] G. Decker, N. Sereno, "Transient Generation of Short Pulses in the APS Storage Ring," these proceedings.
[6] W. Guo et al., "Generating Picosecond X-ray Pulses with Beam Manipulation Synchrotron Light Sources," these proceedings.
[7] B.X. Yang et al., "Streak Camera Studies of Vertical Synchro-Betatron-Coupled Beam Motion in the APS Storage Ring," these proceedings.

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