Commissioning Results of the APS Storage Ring Photon Monitor Systems*

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Abstract

Initial commissionings of the Advanced Photon Source (APS) 7-GeV storage ring and the installed synchrotron radiation monitors have been done. Early studies involved single-bunch measurements on the transverse beam sizes ($\sigma_x \approx 150\,\mu m$, $\sigma_y \approx 50\,\mu m$) and longitudinal profile ($\sigma_\tau \sim 25$ to 50 ps) as a function of stored beam current (0.2 to 7.7 mA). Additionally, the vertical, head-tail instability was purposely induced by decreasing sextupole fields and graphically displayed by the use of a dual-sweep streak camera. These measurements were primarily based on optical synchrotron radiation (OSR). More recent measurements have involved multibunch studies with beam currents up to 100 mA. Progress on the x-ray synchrotron radiation (XSR) imaging station will also be briefly addressed.

1 INTRODUCTION

The commissioning of the Advanced Photon Source (APS) 7-GeV storage ring (SR) [1] was supported by the use of optical synchrotron radiation (OSR) monitors. As reported elsewhere [2] the OSR monitors actually were used for first-turn and single-turn observations in the earliest commissioning phase (which has not been the norm in recent ring commissioning). Subsequently, a series of single-bunch tests were performed during the summer and fall of 1995 which included measurements of the transverse beam size, the longitudinal profiles and bunch length, and the onset of an induced vertical head-tail instability. Although a dual-sweep streak camera has been used previously in the USA on a linac-driven FEL oscillator, these measurements are to our knowledge the first of their kind on a storage ring in the USA.

The commissioning phase then proceeded to multibunch mode and the higher average stored beam currents of 80 to 100 mA. The original water-cooled, commercially available Moly mirror was replaced by a split-mirror followed by an x-ray pinhole station in-tunnel. At high currents the x-ray pinhole images were used for transverse beam profiling and the visible light was still used for bunch length measurements.

2 EXPERIMENTAL BACKGROUND

2.1 Optical Transport

As described elsewhere [2,3], the APS storage ring diagnostics include a dedicated bending magnet source of synchrotron radiation which is detected in both the optical (OSR) and x-ray (XSR) fields. One of the standard 80 dipoles in the main ring (in Sector 35) has been designated for diagnostics imaging use with various photon monitors or detectors employed. Figure 1 shows a schematic of the front-end vacuum transport line which includes the UV-visible pick off mirror. Earliest measurements used a Questar telemicroscope located in the tunnel and focused at the source point in the bending magnet. A charge-coupled device (CCD) camera recorded the beam images, and these were directed through a video mux to a simple TV monitor display, video digitizers, or a video recorder. Using a series of flat mirrors and a spherical focusing mirror, a second configuration brought the UV-visible radiation out of the tunnel and to an optical diagnostics table. This step enabled the employment of a streak camera as well as the CCD cameras. Both the transverse and longitudinal profiles of the stored beam were then obtained.

2.2 Streak Camera Setup

The dual-sweep streak camera system used was a Hamamatsu C5680 generally configured with the synchroscan unit (locked at 117.3 MHz) for the fast vertical deflection and the dual-sweep plug-in operating for the horizontal deflection. The fast axis deflection rate was usually set to cover about a 1000-ps span with $\sigma_{res} \sim 5$ ps for the 30- to 50-ps bunch lengths. (The fastest range

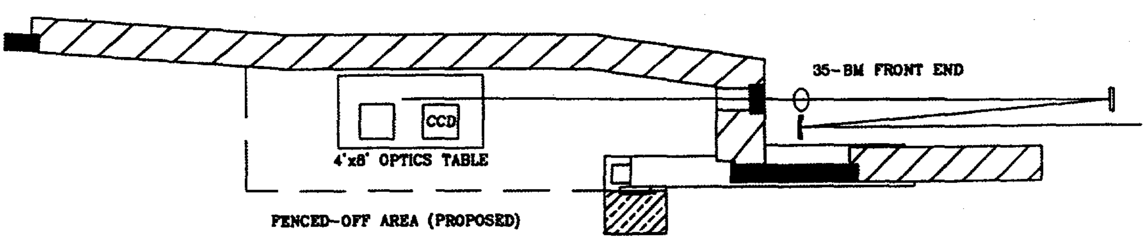

Figure 1: Schematic of the transport line for the UV-visible synchrotron radiation imaging station.

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available would provide a resolution of about 0.6 ps). Since the revolution time in the APS SR is 3.68 μs, dual-sweep spans of 10, 20, and 50 μs were useful for displaying turn-by-turn phenomena. The transport system rotated the image by 90° so the actual vertical profile could be tracked in the head-tail instability experiment.

3 EXAMPLES OF EXPERIMENTAL RESULTS

3.1 Transverse Beam Size

The initial single-bunch, low current (~1 mA) measurements showed beam sizes that were consistent with the baseline design of 8.2 nm-rad natural emittance. As shown in Fig. 2, the horizontal size of $\sigma_x \approx 145\mu m$

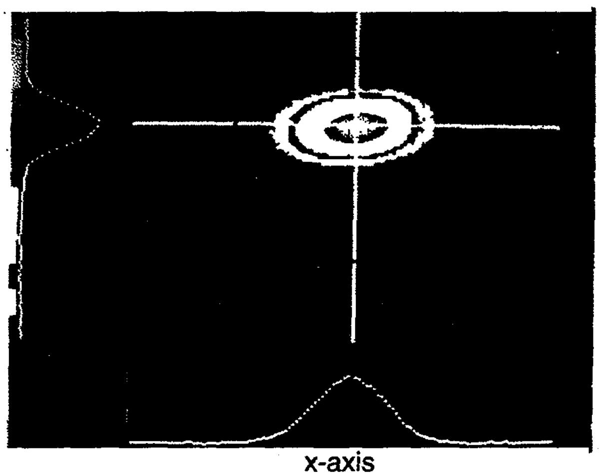

Figure 2: OSR image of the stored beam transverse beam sizes. The beam sizes are consistent with the 8.2 nm-rad natural emittance, assuming the lattice constants are within 10% of other design objectives.

includes contributions from the betatron emittance, the approximate 90 to 100 μm per 0.1% energy spread at this dispersive point in the lattice, and the limiting resolution terms. The use of a 450 x 10 nm bandpass filter resulted in a resolution limit of about σ_{res}–65 ± 10 μm (mostly from diffraction limits). Such a resolution results in a minor correction to the horizontal size observed, but appears to be a limiting factor in the actual vertical beam size observed. In a separate experiment where the vertical coupling was varied, the deconvolved vertical size ranged from $\sigma_y \approx$ 50 to 120 μm. The measurements are consistent with a vertical coupling 3 to 4 times smaller than the 10% baseline value. The measurements were also performed as a function of single-bunch current and no significant size increase was observed from 0.2 to 7.7 mA.

More recently the x-ray pinhole station has been used to provide an on-line monitor at operational currents up to 100 mA. This in-tunnel configuration, with a magnification less than one, has provided a resolution less than 100 μm to date [3].

3.2 Longitudinal Profiles

The early bunch-length and profile measurements were also done in single-bunch mode and, subsequently, as a function of single-bunch current. Initial data on August 19, 1995 were obtained for single-bunch currents up to 7.7 mA (where 5 mA correspondence to 18 mC of charge circulating in the SR). Initial analysis in terms of the Chao-Gareyte parameter showed the bunch length to increase as the one-third power. The raw bunch length vs. current is shown in Fig. 3.

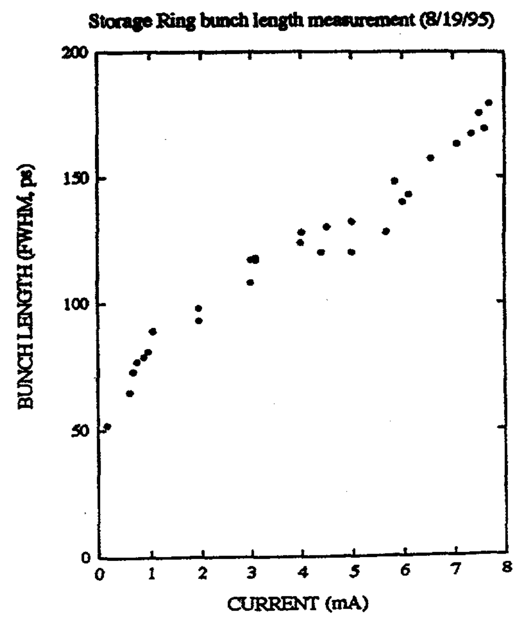

Figure 3: The observed bunch length versus single-bunch current as determined from streak camera measurements.

Subsequent measurements in October 1995 combined with a tracking of the horizontal beam size at a dispersive point indicated that the potential well distortion model simulations were consistent with these data [4].

As part of a demonstration of measurement capability with the dual-sweep streak camera, we purposely induced the vertical head-tail instability by decreasing the sextupole currents (and chromaticity) in the storage ring. The onset of dramatic increase in the transverse vertical profile was first observed (Fig. 4) in focus mode of the streak camera as well as in the CCD camera (a beam-splitter was used to sample the beam). A 40-μm slit limited the x-profile coverage. With the image rotated so that the beam y-profile was on the horizontal display axis, dual-sweep streak operation was initiated. The dramatic difference between the upper and lower images of Fig. 5 are the vertically stable (a) and unstable (b) conditions, respectively. The increase in vertical profile size appears as both a broadening effect and the head-tail kick within the single bunch. The precession of the y-t angle seems to cycle in about 4 turns. This is possibly attributed to the fractional vertical betatron tune of 0.25.

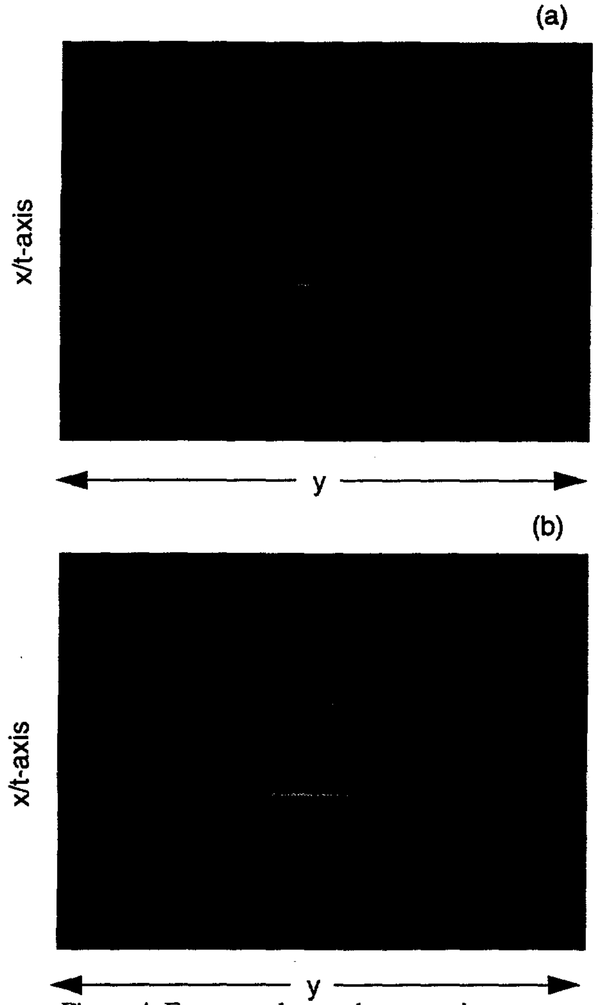

Figure 4: Focus-mode streak camera images showing the change in y-profile (displayed on the horizontal axis) without (a) and with (b) the induced head-tail instability.

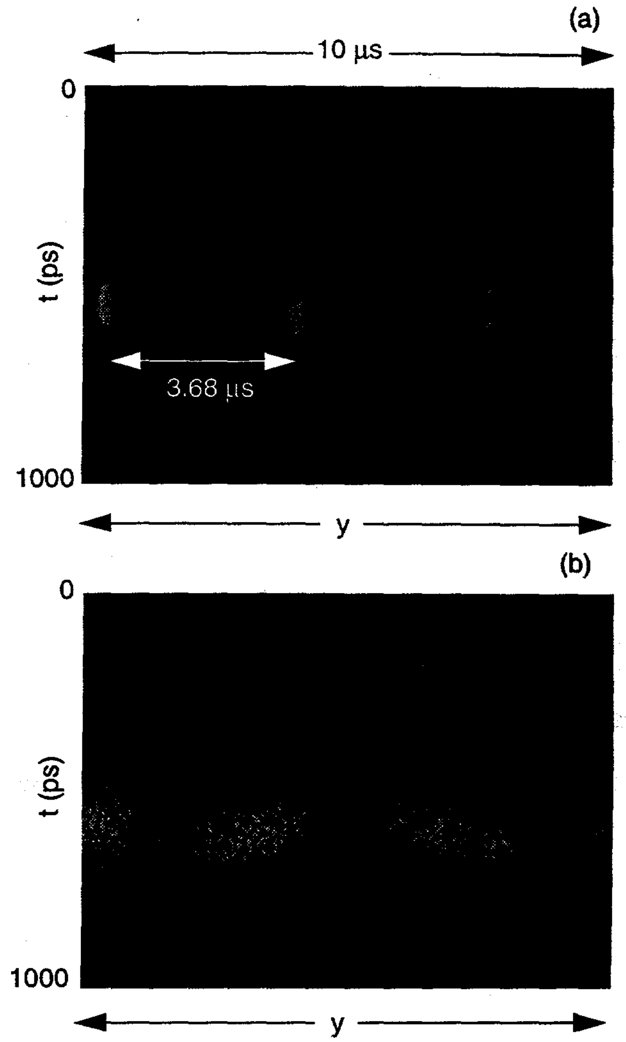

Figure 5: Dual-sweep mode streak camera images showing the change in the y-t profile without (a) and with (b) the vertical instability.

4 SUMMARY

In summary, the implementation of a series of configurations of photon transport of OSR allowed the photon monitor to be active in the earliest stages of commissioning of the APS storage ring. Very early confirmations of the baseline beam sizes and their consistency with the targeted 8.2 nm-rad natural emittance, the inferred 0.1% energy spread, and a vertical coupling of 3 to 5% were obtained. Additionally, early bunch length data vs. single bunch current at lower than baseline rf gap voltages still provided useful information about the approximate impedance of the ring. The dual-sweep streak measurements of the induced vertical head-tail instability are some of the first of their kind in the USA.

5 ACKNOWLEDGMENTS

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