RECENT OBSERVATIONS ON THE APS STORAGE RING USING SYNCHROTRON RADIATION MONITORS*

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Abstract

The Advanced Photon Source (APS) 7-GeV storage ring and our synchrotron radiation diagnostics have matured noticeably in the past year. The monitors now include information from two separate bending-magnet sources (one at a dispersive point in the lattice) as well as a 198-period diagnostic undulator. Data logging via EPICS of the observed transverse beam size is coupled with the measured lattice parameters to calculate emittance on-line as well. Information on the beam emittance (7 ± 1 nm rad) in both the standard lattice and a low β_y lattice, the vertical coupling (1 to 4%), and beam position and jitter are logged. In addition, measurements of divergence, (3 to 7 μrad), beam bunch length (~ 35 ps), and even effects of the moon's gravity on the source point image position have been performed.

1 INTRODUCTION

As the Advanced Photon Source (APS) storage ring (SR) has matured, our diagnostics capabilities using optical synchrotron radiation (OSR) and x-ray synchrotron radiation (XSR) have also been developed. In the 1997-98 period, we have supplemented our initial bending magnet source point imaging lines [1,2] with the recent commissioning of transport lines for a diagnostics undulator and another bending-magnet source at a zero dispersion point in the lattice. Within this period, the SR lattice has also been adjusted for a reduced vertical β value in the straight sections to accommodate a small-gap (5 mm) insertion device vacuum chamber in one area of the ring. The tests on vertical coupling and beam divergence were checked with our full complement of source points. On-line data logging of the beam's transverse size and the calculated emittance based on the measured lattice parameters was done under user conditions. Improvements in the x-ray pinhole camera hardware and image analysis have allowed the detection of the effects of the moon's gravity on the SR effective orbit circumference. This phenomenon has been previously reported using a laser polarimeter at the LEP storage ring [3] and using rf BPMs [4] at the APS storage ring.

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2 EXPERIMENTAL BACKGROUND

The APS storage ring diagnostics have been summarized in more detail elsewhere [5], and the initial OSR diagnostics results were described at PAC'95 [1]. The basic accelerator parameters for diagnostics are listed in Table 1. The fundamental rf frequency is 351.9 MHz with a harmonic number of 1296 in the 1104-m-circumference ring. The revolution period is 3.68 μs with a minimum bunch spacing of 2.8 ns. Our most used fill patterns include a train of 6 consecutive bunches (used for rf BPM electronics) and then sets of 25 triplets about 100 ns apart or 22 singlets about 150 ns apart. Three source points for synchrotron radiation are now imaged: two bending magnets and one insertion device. The natural emittance baseline is 8.2 nm rad.

Table 1: Accelerator Parameters for Diagnostics in the Storage Ring Baseline Design Lattice

Parameter	Storage Ring
Energy (GeV)	7
Natural emittance (nm rad)	8.2
rf freq. (MHz)	351.93
Harmonic no.	1296
Min. bunch spacing (ns)	2.8
Revolution period (μs)	3.68
Design max. single-bunch current (mA)	5
Nominal multibunch current (mA)	100
Bunch length (2σ) (ps)	35-100

Transverse beam profiles and bunch lengths have been measured using both OSR and XSR imaging techniques. In the case of transverse beam size, the visible light pick-off mirror is a single Mo surface whose central region is shadowed from the intense x-rays by a water-cooled copper tube. The visible light is transported out of the tunnel to an optics room. The standard charged-coupled device

(CCD) camera, an intensified, gated CCD camera, and a Hamamatsu C5680 dual-sweep camera are installed on the optics table. Another part of the bending magnet fan of radiation is used for an x-ray pinhole camera that provides superior spatial resolution (~ 35 μm) with an in-tunnel $CdWO_4$ converter crystal and Questar telemicroscope readout by a CCD camera. These images are processed by the Max Video-200 digitizer and an analysis package to provide beam size, position, and calculated emittance.

The diagnostic undulator is a 198-period device with period λ_u = 1.8 cm for a total length of 3.5 m. The fundamental radiation is at about 0.5Å (26 keV) and has a relatively small radiation cone angle of 2.6 μrad. At a distance of 36 m from the design beam waist this contribution to a monochromatized image is smaller than that from the 8-μrad divergence particle beam for the baseline 10% vertical coupling, and design lattice. Vertical coupling of 1-2% is detectable. With the low β_y lattice, the same resolution would support even lower vertical coupling studies.

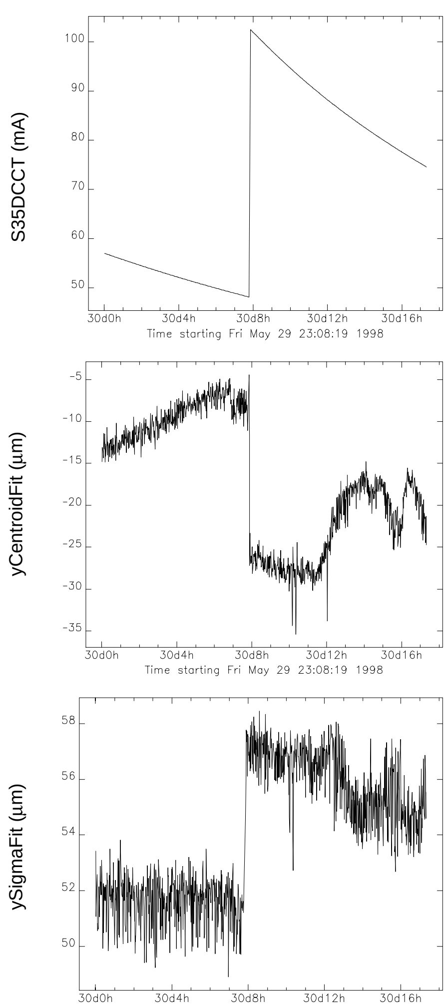

Figure 1: Data logging results for the stored beam current, beam centroid, and beam size for the vertical plane, respectively, from top to bottom.

3 EXPERIMENTAL RESULTS

3.1 Transverse Size and Position

An example of the stored positron beam image from the x-ray pinhole camera was given in Ref. 2. The projected x- and y-axis profiles are fit to a Gaussian function and (for the low β_y lattice) are typically about σ_x ~ 140 μm and σ_y ~ 55 μm. The beam size and centroid are tracked as process variables through the EPICS system for 16 hours on May 30, 1998 as shown in Fig. 1.

By using the measured beta functions, the estimated system resolution, the measured dispersion, and the design energy spread, the beam size data were used to calculate beam emittance on-line in an IOC. Figure 2 shows an example of data logged over the same 16 hours as Fig. 1. The step in measured emittance at about 0800 when the ring is refilled has a correlated step in the image positions shown in Fig. 1. The reduction in horizontal emittance at about 1530 is due to revising the source point β_x value

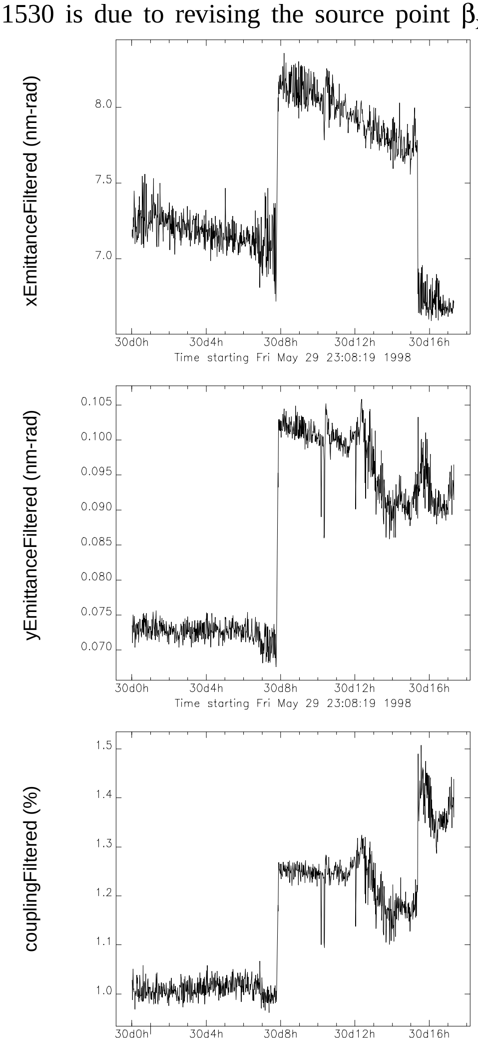

Figure 2: Data logging results for the calculated x-emittance, calculated y-emittance, and vertical coupling, respectively, from top to bottom.

from 1.65 m to 1.88 m. Data logging of these values and the determined coupling have shown the effects of losing the skew-quadrupole power supplies or the sextupole power supplies. In the spring of 1998 with the low β_y lattice, we see values of ε_x = 7.5 nm rad and ε_y = 0.09 nm rad with about ±15% errors estimated. The vertical coupling has consistently been in the 1-2% range.

With an improved system, we were also able to detect a change in the centroid position on a 24-hour cycle. Although we have four times lower dispersion at our source point (75 mm) than at the rf BPMs in the P5 position of the lattice, the effects of the moon's gravity on the orbit circumference were still identified as shown in Fig. 3. The amplitude of the horizontal position shift is about 10 μm in both the nearby rf BPM and the pinhole image compared to the 140 μm (σ) size. Subsequently the rf frequency of the accelerator was controlled via the rf BPM readings at the dispersive point to hold the effective orbit constant for users.

3.2 Divergence

An example image from the diagnostic undulator system was given in Ref. 6. For vertical coupling of 1.6% we have obtained a divergence of about 3.3 μrad when β_y = 10 m. In the low β_y lattice, the β_y ~ 3 m value at the source point results in a larger divergence of about 7.1 μrad.

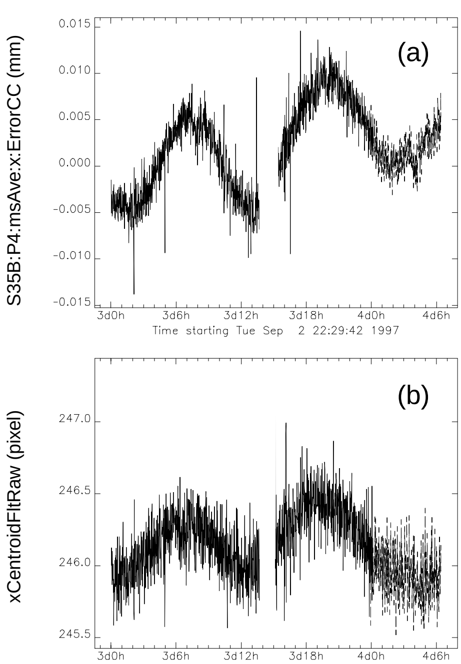

Figure 3: Comparison of the beam centroid position from the nearby rf BPM (a) and the pinhole camera image (b) over ~ 30-hour period. The 10-μm modulation of horizontal beam position over 24 hours is attributed to the moon's gravitational effects on the effective beam orbit circumference.

3.3 Bunch Length

Most of the bunch length measurements have been done with OSR from the bending magnet at a dispersive point in the lattice. The zero-current value is approached at 0.2mA per bunch and has typically been about σ_t = 20 ps @ 1.8 kHz synchrotron frequency. In the user fill pattern with 25 triplets involving a total 90 mA of current, the bunch length grows to about 30 ps. A unique development has recently been achieved using an x-ray streak tube to measure the horizontal beam size and bunch length at the non-dispersive dipole source point [7].

4 SUMMARY

In summary, the synchrotron radiation diagnostics systems on the storage ring have been upgraded and were used to validate and monitor the APS beam quality. The stored beam emittance, vertical coupling, and bunch length are all within specifications. The diagnostics system is undergoing further upgrades on the beamlines to support the future measurements below 1% vertical coupling.

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