OBSERVATIONS OF "EFFECTIVE" TRANSVERSE BEAM-SIZE INSTABILITIES FOR A HIGH CURRENT PER BUNCH FILL PATTERN IN THE APS STORAGE RING*

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Abstract

The x-ray pinhole camera diagnostics on the Advanced Photon Source (APS) storage ring have recorded an "effective" transverse beam size instability during operations with a sextuplet plus 22 singlets fill pattern. These instabilities were not observed with the sextuplet plus 25 triplets fill pattern that has been the standard fill pattern in FY'98. The instability threshold is at 82-85 mA with positrons. The features include an increased average (few seconds) transverse size both horizontally and vertically for stored currents above the threshold with a correlated effect on the beam lifetime. The horizontal transverse emittance is 25-30% larger at 100 mA than below the threshold. There is a related horizontal beam centroid motion as well, but this does not explain the vertical size change nor the lifetime effect. Complementary data were also taken with the diagnostic undulator, and a similar threshold effect on divergence was observed. The cross-comparison of the data and possible mechanisms will be presented.

1 INTRODUCTION

Operations of the Advanced Photon Source (APS) storage ring have included two fill patterns in the last year: one with a bunch sextuplet followed by 25 bunch triplets that were spaced by 102 ns and the other with the sextuplet followed by 22 singlets spaced 148 ns apart. In both cases the total stored current in the ring at the end of the fill is the nominal 100 mA, but in the singlets case the charge per bunch is about three times higher than in each bunch of the triplets. In the singlets-fill case our x-ray pinhole camera diagnostics were used to identify two instabilities that result in increases in averaged transverse beam sizes. One instability occurs only near the maximum beam current in the present conditions, and the horizontal beam size at the dispersive point is dramatically increased. The other is also present down to the threshold of 82-85 mA. Several cross-comparisons of results from both the dispersive and nondispersive bending magnet source points, the diagnostics undulator, and the streak camera bunch length data were used to separate the features of the two instabilities. These features are consistent with a transverse instability with the 82-85 mA threshold and a longitudinal instability at the top of the fill. The first is sensitive to changes in the sets of sextupole currents (chromaticity) and the second to changes in the rf cavity temperature setpoints (HOMs). Representative examples of the different types of data will be presented. The observations were initially performed with stored positrons, but the basic features persisted with the change to electrons in October 1998.

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

2 EXPERIMENTAL BACKGROUND

The APS storage ring utilizes a 7-GeV positron or electron beam (since Oct. 1998) circulating in a 1104-m circumference ring. Normal stored beam currents are 100 mA with a natural emittance, $\varepsilon = 7.9 \pm 1.1$ nm rad. The baseline vertical coupling was 10%, but we now generally run at the 1-2% level. The standard fill pattern involves a sextuplet (each of similar intensity) totaling 10 mA of stored beam current. The other 90 mA are distributed in 25 triplets spaced 102 ns apart in the ring. In a special user mode we have run ~15 mA in the sextuplet and 85 mA distributed in 22 singlets that are 148 ns apart. It is this latter fill pattern with about three times the charge per bunch that has exhibited the "effective" transverse beam size growth. These phenomena have been detected with photon diagnostics, rf BPMs, and the tune measurement system. This paper will concentrate on the photon diagnostics results.

The photon diagnostics are located in one of the 40 sectors of the APS [1-3]. We use radiation from bending magnets and a diagnostics undulator as shown in Fig. 1. For the dipole magnet source at a dispersive point in the lattice, both x-ray synchrotron radiation (XSR) and optical synchrotron radiation (OSR) techniques are used. An in-tunnel x-ray pinhole camera includes a remotely controlled four-jaw aperture at 9.1 m from the source, a $CdWO_4$ or YAG:Ce converter crystal at 17 m from the source, and a charge-coupled device (CCD) camera. Effective spatial resolutions of about 25 μm (σ) are estimated. The video is digitized by a Data Cube MaxVideo-200 (MV200) unit, and the digital results are identified as process variables (PVs) for the EPICS platform. Data logging of beam size, centroid, and emittance can thus be done on a 24-hour period. The OSR is transported out of the tunnel to an optics station where a CCD camera, a Stanford Computer Optics (SCO) Quik-05 gated camera, and a Hamamatsu C5680 dual-sweep streak camera are available. The synchroscan unit is phase locked to 117.3 MHz, the third subharmonic of the SR rf

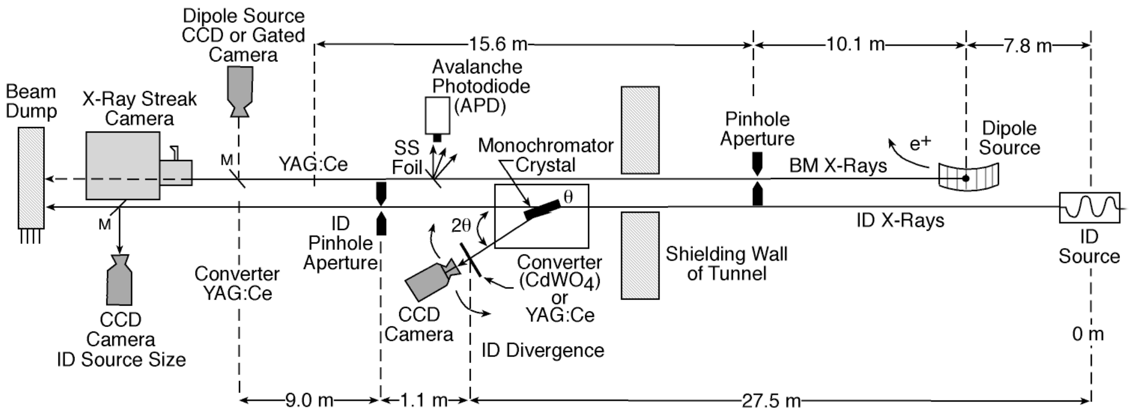

Figure 1: A schematic view of the dipole and diagnostics undulator beamline. On the undulator line the monochromator and pinhole are indicated. On the dipole source the aperture is in the tunnel, and the converter and camera are indicated.

master oscillator. In these studies the streak camera was used to monitor changes in average stored beam bunch length as a function of current. The streak images also were processed by a second MV200 and tracked.

Additionally, the nearby diagnostics undulator and low-dispersion-point dipole source beamline were used as warranted. As schematically shown in Fig. 1, the undulator radiation (UR) is used with the single-crystal monochromator for divergence information and the subsequent four-jaw aperture for horizontal beam-size information [4,5]. The divergence resolution is about 2.6 μrad (σ) and the pinhole resolution is about 60 μm (σ).

3 EXPERIMENTAL RESULTS AND DISCUSSION

In this section representative examples of results from the different sources and for the two principal instabilities will be presented. The EPICS data logger and a second MV200 allowed us to select different image sources while keeping the x-ray pinhole camera as a reference for each 12-hour stored beam decay period.

3.1 Transverse Instability

The basic observation in the x-ray pinhole data is the increased averaged horizontal beam size for some current levels. We attribute this size increase to both a measured centroid oscillation at the fractional betatron tune of 0.20 and an intrinsic size increase of some kind. In Fig. 2 the effects are plotted versus stored positron beam current. Both the horizontal beam size and emittance in Fig. 2a and 2b, respectively, are larger above ~85 mA. There is a correlated change in the slope of beam lifetime versus current also at ~85 mA as seen in Fig. 2c. In fact, the correlated change in lifetime seen in Fig. 2 is why we do not attribute only a centroid motion to the observed increase in transverse horizontal size. The only effect in the streak camera data was the expected gradual decrease in bunch length with decrease in single-bunch current.

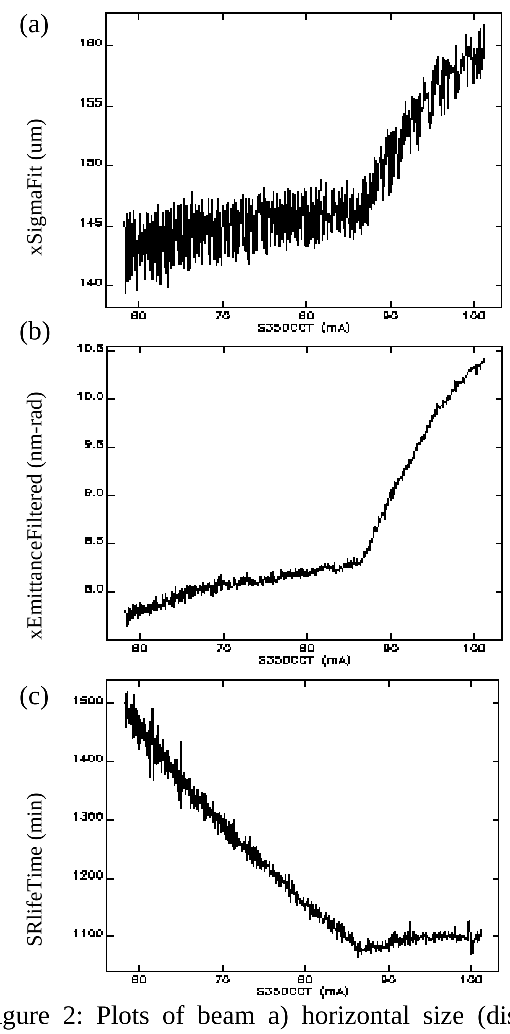

Figure 2: Plots of beam a) horizontal size (dispersive point) and b) horizontal emittance, and c) stored beam lifetime versus stored beam current. There is a correlated change in the respective slopes at ~85 mA of stored positrons.

During the stored electron beam runs in Dec. 1998 the x-ray pinhole camera data were compared to the ID divergence data, the ID pinhole data, lifetime data, and the streak camera. Correlated changes were seen in the first two horizontal transverse sizes, as shown in Fig. 3, and also with the lifetime.

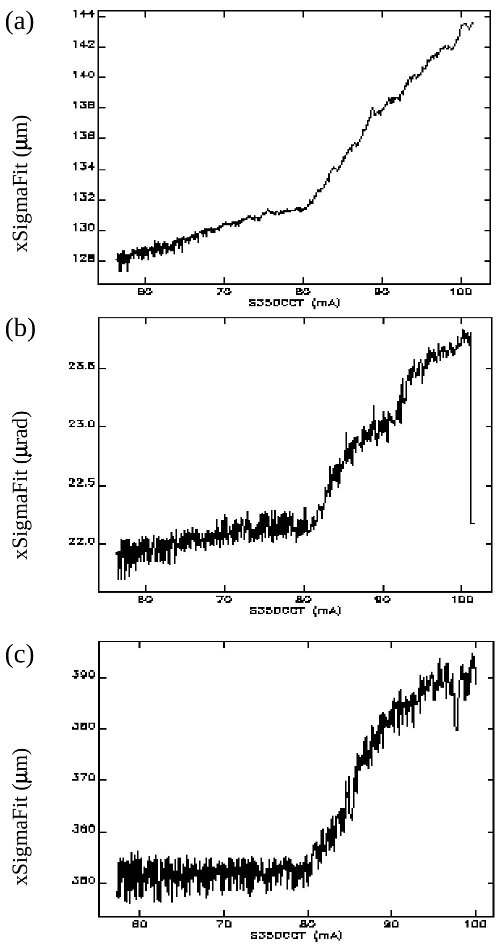

Figure 3: Plots of the variation with current of stored electron beam a) horizontal size at a dispersive point, b) horizontal divergence, and c) ID source point size. All have the increased values above 85 mA.

3.2 Longitudinal Instability

In this case at currents around 101 mA, the observed horizontal beam size shows growth from 140 to 260 μm as shown in Fig. 4a. In Fig. 4b the beam bunch length change from 35 ps to 70 ps is shown over the same 10-min period. An effect in longitudinal phase space is clearly supported.

Additionally, the nature of the bunch length blurring is related to a phase instability detected by a dual-sweep streak camera. A synchrotron oscillation can also develop over the many turns at 1.8 kHz. The superposition of the two effects gives the 30-ms averaged bunch-length change from 35 ps to 70 ps (σ).

The magnitude of this effect was sensitive to the rf cavity temperature and was reduced by changing the rf cavity temperature setpoint. It is suspected that the higher-order modes (HOMs) are strongly temperature dependent and are contributors to the effects observed.

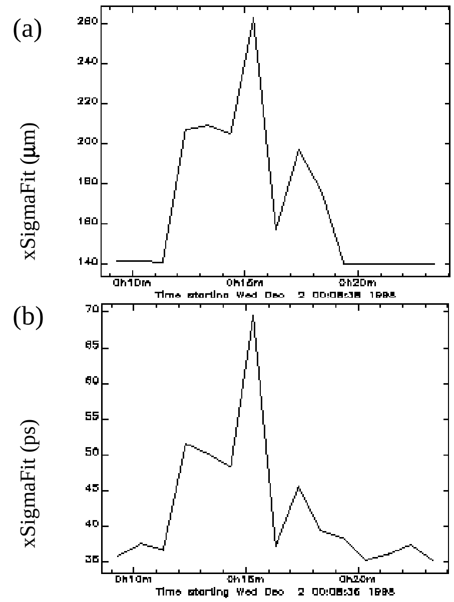

Figure 4: Plots of the correlated change in a) horizontal beam size at a dispersive point and b) the beam bunch length near 101-mA stored beam currents. These are consistent with a longitudinal instability.

4 SUMMARY

In summary, we have used the correlated observations of beam transverse size, beam divergence, and bunch length to sort the features of the two instabilities that cause an increase in effective beam size. The evidence is consistent with a transverse instability with a threshold at 80-85 mA that can be controlled with increased chromaticity. The longitudinal instability near 101 mA (at present) is controlled by rf cavity temperature setpoints. Further experiments with a gated camera to search for horizontal quadrupolar effects or energy centroid shifts may be of interest. We are now in position to provide a more stable singlets-fill beam for the users, and this was successfully done in March 1999.

5 REFERENCES

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