AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0 5.6 6.3

MANUFACTURED TO AIIM STANDARDS

BY APPLIED IMAGE, INC.

1 of 1

Conf-940613--26

ANL/ASD/CP--81725

Proposed Time-Resolved Photon/Imaging Diagnostics for the APS*

A. Lumpkin, W. Sellyey, and B. Yang

Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439, USA

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract W-31-109-ENG-38.

Proposed Time-Resolved Photon/Imaging Diagnostics for the APS*

A. H. Lumpkin, W. Sellyey, and B. Yang
Argonne National Laboratory, Argonne, IL 60439, U.S.A.

Abstract

Plans for time-resolving the synchrotron radiation emitted by circulating particle beams and characterizing parameters of those beams for the three rings in the Advanced Photon Source (APS) are briefly presented. The APS includes a 450-MeV positron accumulator ring (PAR), a 0.45-to-7-GeV injector synchrotron (IS), and the 7-GeV storage ring. Both imaging and photon area detector principles are used for time-resolved information. Gated, intensified cameras and synchroscan and dual-sweep streak cameras will be used to assess single bunch, bunch-to-bunch, or turn-to-turn phenomena. Both the transverse and longitudinal phase space effects can be tracked. An example of the transverse damping in the PAR at 250 MeV and initial tests in the lab of the dual-sweep streak camera will be presented.

1. INTRODUCTION

The challenges of understanding the particle-beam parameters of a third-generation synchrotron radiation facility such as the Advanced Photon Source (APS) include time-resolved transverse and longitudinal emittance characterizations. The APS includes a 450-MeV positron accumulator ring (PAR), a 0.45-to-7-GeV injector synchrotron (IS), and the 7-GeV storage ring [1]. The storage ring has a natural transverse emittance of 8 x 10^{-9} m rad, and with 10% vertical coupling the expected spot sizes are about $\sigma_{x,y}$ = 110 µm at a bending magnet point of the lattice. The momentum spread is nominally 0.1% with a bunch length σ_t ~17 ps at low current. Gated, intensified cameras and synchroscan and dual-sweep streak cameras working in the UV and x-ray photon fields will be used to assess single bunch, bunch-to-bunch, single turn, and turn-to-turn phenomena. Both the transverse damping and longitudinal damping can be tracked under normal conditions in any of the rings. An example of the transverse damping observed in the PAR at 250 MeV, calculations of longitudinal damping in the storage ring, and initial tests in the lab of the dual-sweep streak camera will be presented.

2. BACKGROUND

The general features of the three rings at APS are shown in Table 1. The PAR revolution time is the shortest at 102.3 ns with IS and storage ring at 1.23 and 3.68 µs, respectively. For the longer bunch lengths of the PAR, which even after damping would be about 300 ps, a fast photodiode will be used. For the IS and SR, the fast photodiode and the dual-sweep streak camera will be used.

In all three rings, at least one bending magnet vacuum chamber will have a port to allow extraction of the emitted synchrotron radiation. One mirror is in vacuum and directs the radiation to the optical transport line. At this time both PAR and IS have two such viewing points.

Table 1. APS Parameters for Beam Diagnostics in the Three Rings.

	PAR	IS	SR
RF FREQUENCY	9.77 or 117 MHz	351.93 MHz	351.93 MHz
REVOLUTION TIME	102.3 ns	1.228 us	3.68 us
NUMBER OF BUNCHES	1	1	1 to 50
MIN BUNCH SPACING	—	—	20 ns
BUNCH LENGTH	30 ns < 0.29 ns / 0.32 ns	122 ps	35 to 100 ps
MIN AVE BEAM CURRENT	1.4 mA (1 linac pulse injected)	—	0.22 mA (for single bunch)
MAX AVE BEAM CURRENT	33.4 mA (24 linac pulses injected)	4.7 mA	5 mA (for single bunch)
MAX INTENSITY	3.6 x 10^{10} (24 linac pulses injected)	3.5 x 10^{10}	2.2 x 10^{10} (per bunch per mA)

3. EMITTANCE MEASUREMENT CONSIDERATIONS

3.1 Stored Beam, Transverse Measurement

In the APS bending magnet source β_x and β_y are about 1.7 m and 18 m, respectively. At the baseline 10% vertical coupling, we expect transverse profiles with $\sigma_x \approx$ 110 µm and $\sigma_y \approx$ 100 µm. For imaging in the ultraviolet with λ ~ 220 nm, we expect a diffraction limit (σ_{DF}) $\approx$ 40 µm so reasonable quantitative measurements are possible. For 1% vertical coupling, the implied vertical profile reduces by $10^{1/2}$ to about σ_y = 35 µm. So for this push in the accelerator parameters we intend to use x-ray pinhole imaging with an aperture of about 10-µm diameter, and a magnification of 4 to 5. The pinhole resolutions (σ_{ph}) would then be about 15 µm and allow us to even push towards the 0.1% vertical coupling regime from the diagnostics point of view. Recent tests at NSLS have reported 0.2% vertical coupling [2]. A schematic for the beam profile imaging using either the UV or x-ray components of synchrotron radiation is shown in Fig. 1.

In the case of either ultraviolet synchrotron radiation imaging or x-ray synchrotron radiation imaging, we expect to use gated, intensified cameras to allow single bunch, single turn profile measurement capability. Figure 2 shows an example from the 250-MeV operations in PAR where the damping time is about 120 ms. The series of images are acquired at 15 Hz with a 33 ms sampling time. The horizontal

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

betatron damping process is projected onto this view as two spots about 10 mm apart which damp to one spot (orbit position) of a few mm in diameter (FWHM). In subsequent operations of 350 MeV, the damping time is much faster. Attenuation filters of about ND 4.0 are used on the cameras with 1-2 nC circulating.

An additional complementary approach will be based on the known effects of particle beam quality on observed undulator radiation properties [3]. The opening angle of the bending magnet synchrotron radiation at 7 GeV is about 70 μrad and this is unfortunately large compared to the 7-μrad particle beam divergence. One might attack this by using either an $N > 100$ period undulator to reduce the divergence by a factor of 10 or a coupled undulator approach where $N_D \sim 100$. Both options are under consideration at this time. The more recent formalism involving Twiss parameter determination from undulator radiation is of particular interest [4].

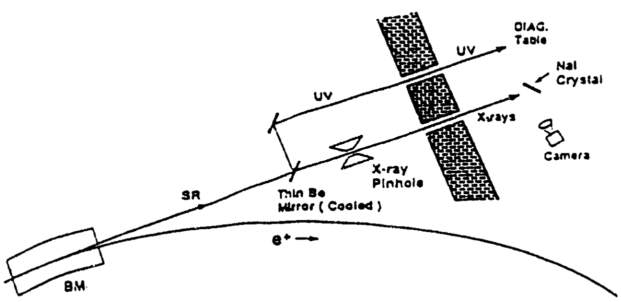

Fig. 1. A schematic of the positron beam imaging via bending magnet synchrotron radiation (UV and x-ray components).

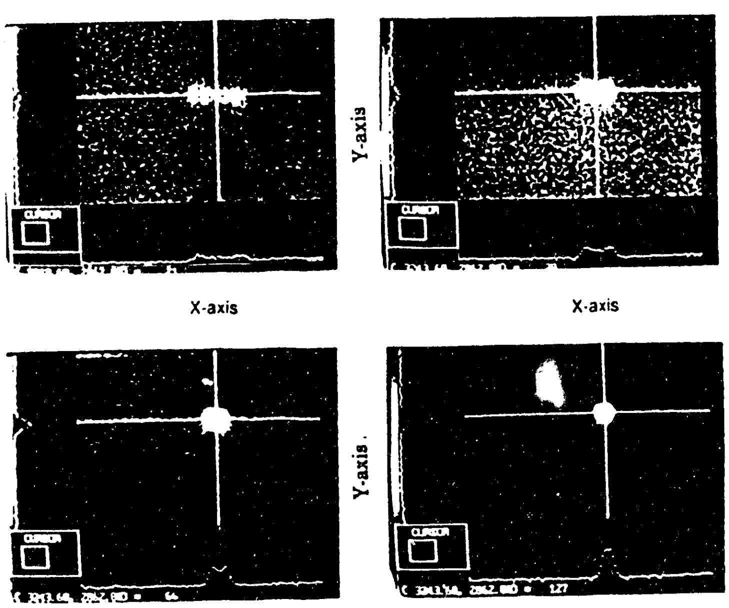

Fig. 2. Sequence of video images showing horizontal damping of the beam in the PAR.

3.2 *Stored Beam, Longitudinal Measurement*

The beam initially injected into the storage ring will undergo a longitudinal damping process as well. The final bunch length attained will likely depend on beam current/bunch and the magnitude of various wakefield effects. In an earlier workshop to address the possible instabilities in APS, it was estimated the bunch length would be ~30% longer for the 5-mA/bunch case than the low current case [5]. Recently, L. Emery has started a series of calculations of the dynamics of longitudinal phase space during the damping process [6]. The projections on the time or phase axis are directly addressable by synchroscan and dual-sweep-streak camera techniques demonstrated on linac beams, undulator beams, and in the last few years at Tristan and LEP as well [7]. For APS the expected baseline will be $\sigma_t \sim 17$ ps, after damping from the synchrotron ($\sigma_t \sim 60$ ps). The dynamics of these parameters are quite interesting, as shown in Figs. 3-5. In Fig. 3 the actual bunch length variation is plotted turn by turn. On the time scale of turns (at 3.68 μs per turn), noticeable oscillations are seen every 72 turns. In Fig. 4, the average phase position is shown with a phase position variation from 0 to -16 ps. This is easily tracked simultaneously with the bunch length by the dual-sweep streak technique. The energy spread and central value is also dynamic, and Fig. 5 shows the energy vs. phase space on a time track as the beam "spirals" in to the final location in the 2-D space. The projections in the time axis are already addressed; the average energy projections could be assessed by a BPM located in a dispersed region or by time-resolving the undulator spectrum. The same image processing system can process the observed profiles and positions for phase and bunch length measurements at 5-10 Hz.

A laboratory simulation of the operation of a dual-sweep streak camera to assess a 50-ps (FWHM) (or $\sigma_t \approx 20$ ps) pulse is shown in Fig. 6. The Hamamatsu model 5680 streak camera tracked a multiple trigger ps light source. The two scales are 5-μs and 1500 ps. The 117.3-MHz frequency was not phase-locked to the pulsed light source so the phase position does move during the 5 μs. The individual 50-ps pulses are easily seen in the pseudo-3D display.

4. SUMMARY

In summary, the evaluation of stored beams in the three rings at APS will include time-resolved measurements of the projections from the transverse and longitudinal phase space. The very slow transverse damping measurement in the low-energy PAR case will be extended to the much faster damping times of the storage ring at 7 GeV. The potential for detection of beam instabilities as the operating parameter space is pushed will be available through gated cameras and dual-sweep streak camera techniques.

5. ACKNOWLEDGMENTS

The authors acknowledge the damping simulation provided by L. Emery (APS) and the assistance of W. Cieslik of Hamamatsu Photonics during the streak camera test/evaluation.

6. REFERENCES

[1] D.E. Moncton, E. Crosbie, and G.K. Shenoy, "Overview of the Advanced Photon Source," Rev. Sci. Instrum, 60, (7), July 1989.

[2] J. Safranek and S. Krinsky, "Plans to Increase Source Brightness of the NSLS X-ray Ring," Proceedings of the 1993 Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

[3] P. Elleaume, Journal de Physique, C1, no. 2, Tome 44, Fevrier 1983, C1-333.

[4] F. Ciocci, G. Dattoli, and A. Torre, "The Effect of Emittance Inhomogeneous Broadening on the Magnetic Undulator Brightness," submitted to IEEE, J. Quantum Electronics, 1993.

[5] Proceedings of the Impedance and Bunch Instability Workshop, Argonne National Laboratory, Argonne, Illinois, Oct. 31-Nov. 1, 1989, ANL/APS/TM-5 (April 1990).

[6] L. Emery (Argonne National Laboratory), private communication, May 1993.

[7] A.H. Lumpkin, "RF-Synchronized Imaging for Particle and Photon Beam Characterizations," Proceedings of the 1993 Particle Accelerator Conference, Washington, DC, May 17-20, 1993, and references therin.

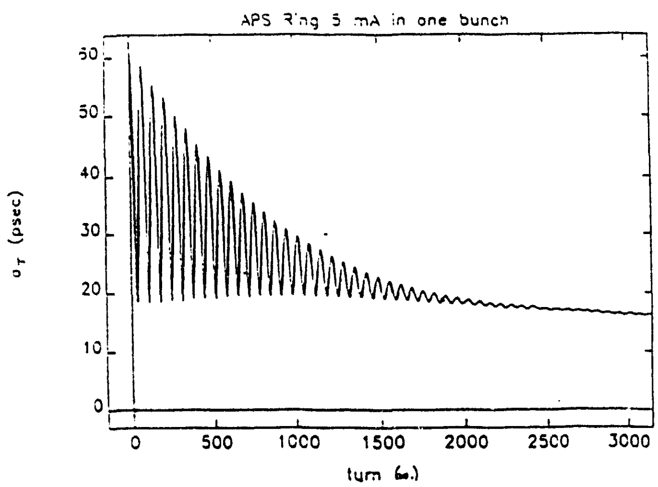

Fig. 3. Simulation of the damping of the positron bunch's temporal length versus turn number in the storage ring.

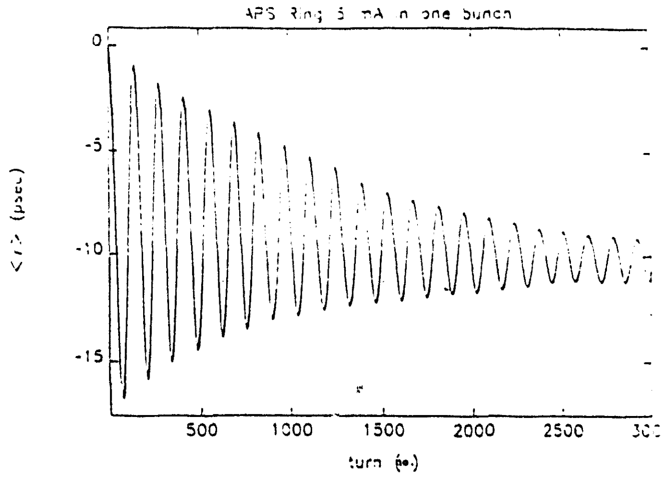

Fig. 4. Simulation of the variation of bunch phase during damping in the storage ring.

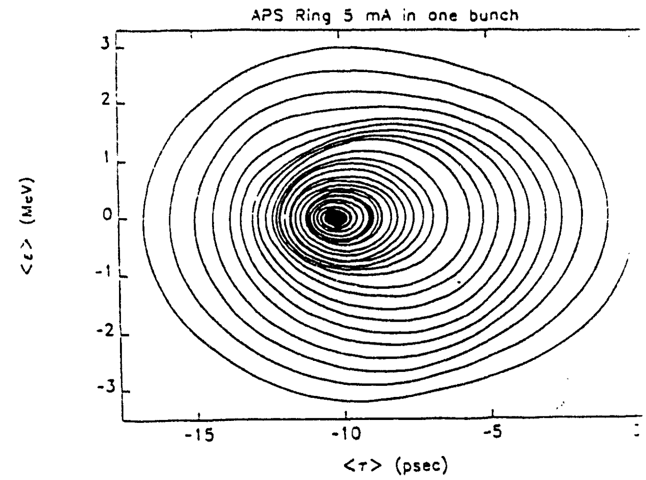

Fig. 5. Simulation of the longitudinal phase space (average energy and average phase) damping dynamics in the storage ring.

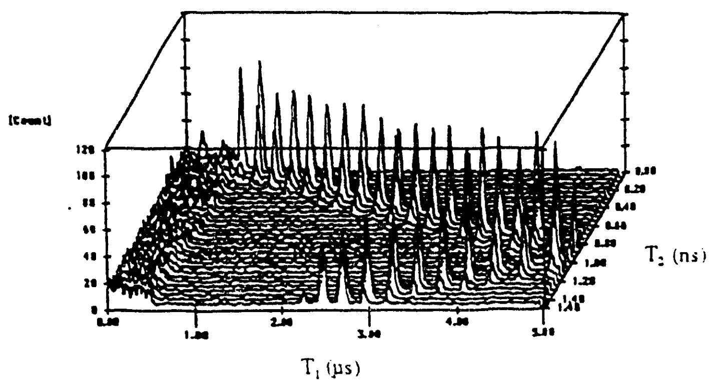

Fig. 6. Pseudo-3D display of the dual-sweep streak camera image of the 50-ps test source. The horizontal axis span is 5 μs and the vertical axis is 1.5 ns.