STREAK CAMERA MEASUREMENT OF ELECTRON BEAM ENERGY LOSS PER TURN IN THE ADVANCED PHOTON SOURCE PARTICLE ACCUMULATOR RING

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ABSTRACT

- Relativistic electron beams in storage rings radiate a significant fraction of beam energy per turn.
- As demonstrated in previous experiments, with the radiofrequency accelerating structures off, the turn-by-turn time of arrival of the electron bunch can be observed from the synchrotron radiation that it produces using a streak camera.
- In the present work, we present measurements of the energy loss per turn of an initially short electron bunch (~1 ps RMS) from a photocathode electron gun in the Advanced Photon Source Particle Accumulator Ring (375 MeV, 102 ns revolution period).
- With the streak camera synchroscan locked to the twelfth harmonic of the revolution frequency (117.3 MHz), we observe an injection transient in the horizontal direction.

MOTIVATION

- The energy loss per turn due to incoherent synchrotron radiation has previously been observed at GeV-scale electron storage rings [1, 2]. In those experiments, the electron beam was injected into the storage ring with the RF cavities switched off.
- In the present work, dual-sweep streak camera measurements were performed, showing energy spread effects on the bunch length per turn, electron beam energy loss per turn, and the injection transverse transient for the initial ~1 ps duration bunch injected at 375 MeV.

THEORY

- An electron loses energy U_0 each turn due to synchrotron radiation. It follows a dispersive orbit and arrives earlier each turn. The change in arrival time of the electron is given by [1]:

$$\Delta T_{\mathrm{tot}} = \frac{f_0}{2E}\alpha_c U_0 t^2$$

where f_0 is the revolution frequency, E is the electron beam energy, and α_c the momentum compaction factor.
- Injection transients have previously been observed using turn-by-turn optical measurements. Beams injected off-axis are observed to oscillate at the betatron frequency in the plane of the orbit offset. In the PAR, electrons are injected with a horizontal offset.
- Beam centroid oscillations are observed at the betatron frequency if there is a dispersion mismatch, and oscillate at twice the betraton frequency if there is a beta function mismatch [3].

METHOD

- A chain of injectors is used to accelerate electrons at the APS. We utilise electron beams from the photocathode gun and RF thermionic gun, which are accelerated using the main linac accelerating structures.

Table 1: PAR Parameters for the Present Experiment

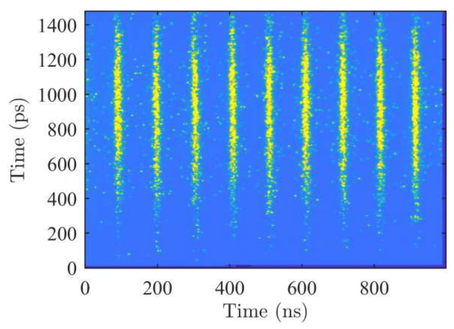
Parameter	Symbol	Value	Units
Beam energy	E	0.375	GeV
Revolution period	T	102	ns
Betatron tune (x)	ν_x	2.177	–
Betatron tune (y)	ν_y	1.211	–
Momentum compaction factor	α_c	0.244	–
Second synchrotron radiation integral	I_2	6.16	m^{-1}
Energy loss per turn	U_0	1.72	keV

- To observe the electron beam arrival on a turn-by-turn basis, we used a streak camera installed at the PAR West synchrotron light port: a location in the lattice with non-zero horizontal dispersion [4, 5].
- The Hamamatsu model C5680 streak camera was operated in the dual-sweep configuration. A synchroscan module was used as the deflector in the vertical plane, on sweep range 4 (3.0 ps per pixel). A slow dual axis unit was used as the horizontal deflector, varying the sweep range between 1–10 μs (10–100 turns of the PAR).

RESULTS

Stored at Equilibrium

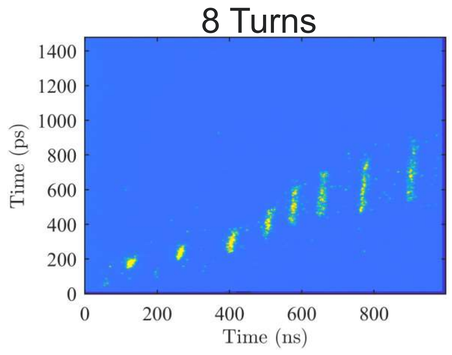
Observation over 9 turns of the PAR of a single electron bunch stored beam at equilibrium, with both the fundamental and 12th harmonic RF cavity on.



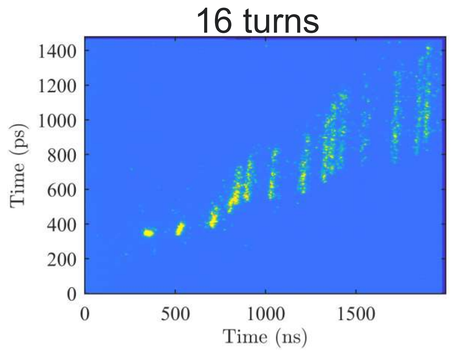
Confirmed that damped electron bunches arrive at an equal revolution period of 102 ns. Equilibrium bunch length was determined to be ~300 ps from the image vertical axis.

Photocathode Gun Injection

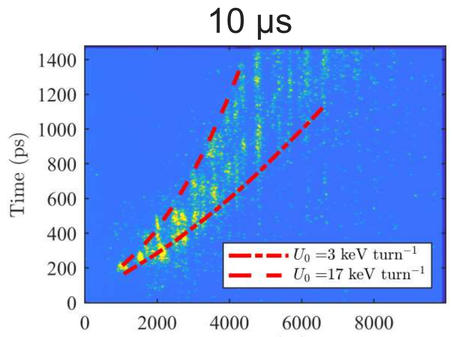
8 Turns



16 turns

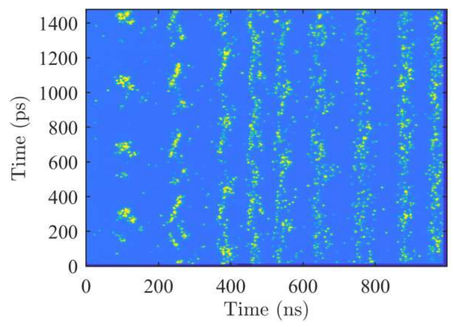


10 μs



To observe longitudinal electron beam dynamics at injection, we accelerate a single ~1 ps electron bunch from the photocathode gun using the linac, and inject it into the PAR with the RF off.

RF Thermionic Gun Injection



We accelerated a ~10 ns duration electron bunch train from an RF thermionic gun using the linac, and injected it into the PAR with the RF off.

SUMMARY

- Transverse injection transient results in the shift of the beam image away from regular spacings along the slow (horizontal) time axis.
- Period of oscillation approximately fractional horizontal betatron period.
- Parabolic fits for the energy loss per turn are presented, bounding the time of arrival of the electron beam envelope. Could be a mismatch of the beam energy with the ring at injection [2], or coherent synchrotron radiation.

CONCLUSION

- Using a streak camera, we have observed the time of arrival and bunch lengthening of a ~1 ps electron bunch for the first few turns of the PAR.
- With the streak camera synchroscan unit, we observe an injection transient in the horizontal direction.
- An energy loss per turn of the electron beam was observed to be $3\ \mathrm{keV\ turn^{-1}} \leq U_0 \leq 17\ \mathrm{keV\ turn^{-1}}$ compared to the model of $U_0 = 1.7\ \mathrm{keV\ turn^{-1}}$.

REFERENCES

[1] J. M. Byrd and S. De Santis, Phys. Rev. ST Accel. Beams, vol. 4, p. 024401, 2001.
[2] A. A. Nosych *et al.*, in *IBIC'18*, pp. 548–551.
[3] M. G. Minty and W. L. Spence, in *PAC'95*, pp. 536–538.
[4] A. H. Lumpkin, *AIP Conf. Proc.*, vol. 229, pp. 151–179, 1991.
[5] A. Lumpkin and B. Yang, in *PAC'95*, pp. 2470–2472.

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