Progress towards Top-Up Mode Operations at the Advanced Photon Source

L. Emery, M. Borland

Argonne National Laboratory, 9700 South Cass Avenue, IL 60439

Goals and Definitions

Top-up Injection

Injection into the storage ring while any photon shutter is open.

Top-up Operation

Top-up injection used to maintain a constant level of current stored in the storage ring within some tolerance, $\varepsilon > \left|(I - I_0)/I_0\right|$

Motivation

Improves x-ray beam position stability through

- Constant heat load on X-ray optics
- Constant heat load on storage ring components
- Constant signal strength for beam position monitors

Much less concerned with beam lifetime.

Relative current stability goals

Long term: $\varepsilon = 10^{-4}$. Achieved for a few hours of running during machine studies.

Short term: $\varepsilon = 10^{-3}$. Achieved routinely and has been delivered to users for several hours for trial.

Beam disturbance from Injection process

Reduces X-ray brightness for a few 10s of ms at every pulse. Steps have been taken to reduce the impact of injection transients on X-ray experiments.

Radiation Safety Concerns

Open photon shutters may allow an injected beam to escape the SR enclosure under certain conditions. A fully or partially shorted dipole is a necessary condition.

Simulations

Analytical estimates [1] and simulations [2] of fault conditions show that, given the apertures and other hardware, one cannot have stored beam while extracting an injected beam out of the SR enclosure.

Hence, we ensure top-up safety with an interlock that inhibits top-up injection when there is no stored beam.

Fault conditions simulated:

- partial short of a dipole plus mis-set quadrupole.
- partial short of a dipole plus shorted multipoles producing a compensating dipole kick.
- all of the above plus injection beam energy error.

[1] L.Emery, M.Borland, “Analytical Studies of Top-Up Safety at the Advanced Photon Source,” Proceedings of 1999 Particle Accelerator Conference, pp. 2939-2941.

[2] M.Borland, L.Emery, “Tracking Studies of Top-Up Safety at the Advanced Photon Source,” Proceedings of 1999 Particle Accelerator Conference, pp. 2319-2321.

Radiation Safety Concerns (cont'd)

Apertures

The SR and photon beamline apertures limit the possible trajectories of the injected beam.

Controlled drawings and documents list the relevant apertures and their position tolerances.

Aperture positions are periodically checked by indirect measurement of external points of vacuum chambers (VC). Checks on VC positions consist of

- testing VC/magnet relative positions with a measurement gauge at the end of every shutdown
- a regularly scheduled magnet survey.

Other Operational Concerns

Transport Line Diagnostics

For $\varepsilon = 10^{-4}$ stability, charge per pulse is about 0.04 nC, which is at the bottom range of sensitivity.

- Higher sensitivity diagnostics are planned.
- Scraper can be used to reduce the charge just upstream of the injection point.

Radiation Dose in Insertion Devices (IDs)

IDs can be demagnetized by a large radiation dose.

It is physically impossible for shielding to protect the IDs completely.

Cherenkov detector installed for real-time loss monitoring.

Injection efficiency

Small apertures and pulse-to-pulse variation of septum magnets reduce efficiency.

Virtually 100% injection efficiency is obtained by using a mismatched kicker bump.

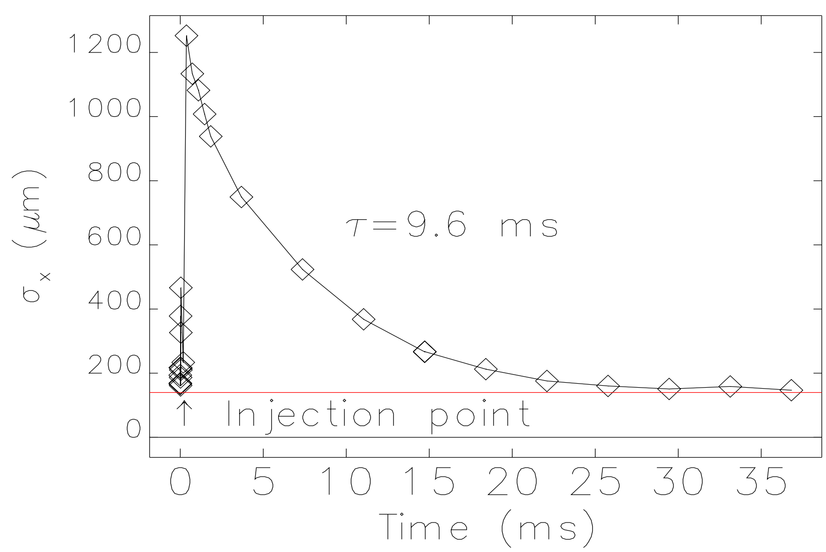
Beam Perturbation

Stored beam centroid motion or increased emittance will reduce the X-ray brightness.

Mismatched injection bump

Imparts a betatron amplitude of a few mm that decoheres in about 20 turns, replacing centroid motion with increased emittance.

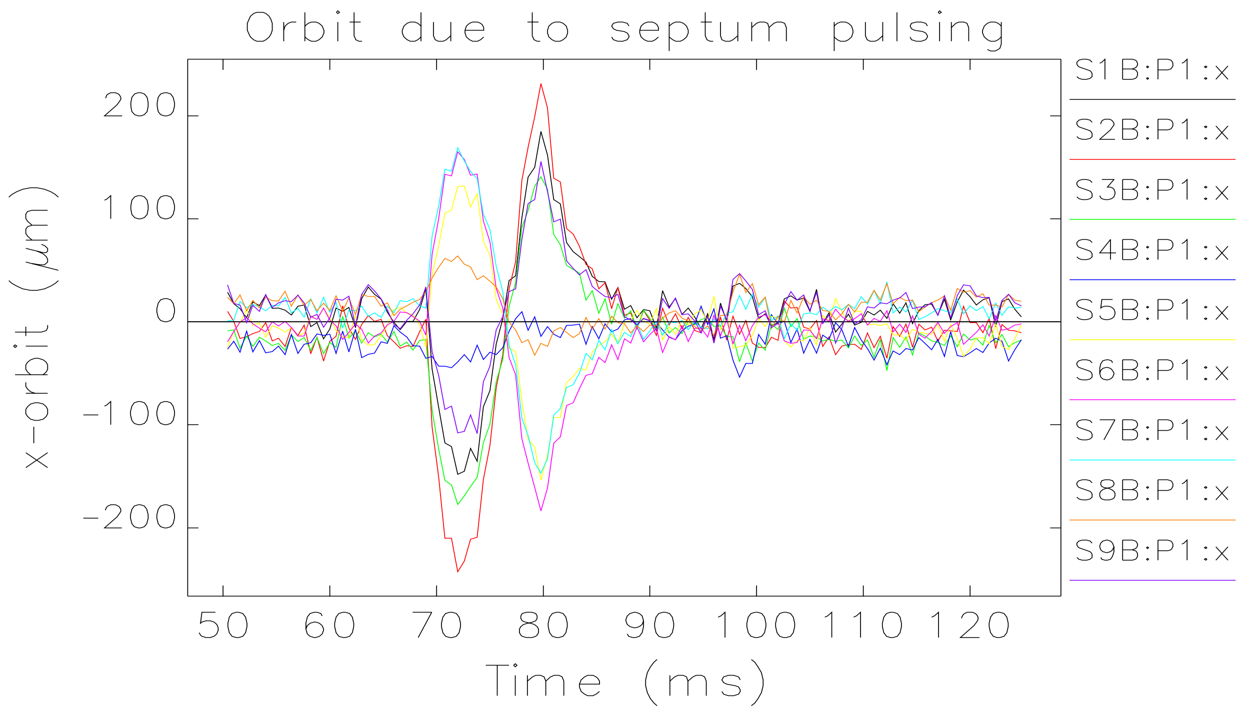
Emittance blow-up (up to 40x) lasts 30 ms.



Blow-up will be reduced when aperture problems are fixed which will allow a matched kicker bump.

Septum leakage field

Produces a closed orbit disortion of ~200 µm lasting about 25 ms.



Remainder will be corrected using the real-time orbit feedback system gated into a feed-forward mode.

BPM xy coupling

BPMs in small gap chambers have a strong coupling between horizontal beam size and y-readback for vertically displaced beam. Real-time orbit feedback must be gated off for 30 ms.

Beam Perturbation (cont'd)

Gating of data acquisition

Injection-related signals are available to X-ray experimenters to block possible spurious data during the injection event.

This was used successfully with users during machine studies.

Gating off of 35 ms of beam time every two minutes still provides a 99.97% duty factor.

Gating is not compatible with CCD camera experiments which require uninterrupted beam.

Hence, for now we must increase the injection interval, say one to several hours following a strict schedule.

This mode does not provide all the advantages of top-up, but can significantly increase X-ray availability.

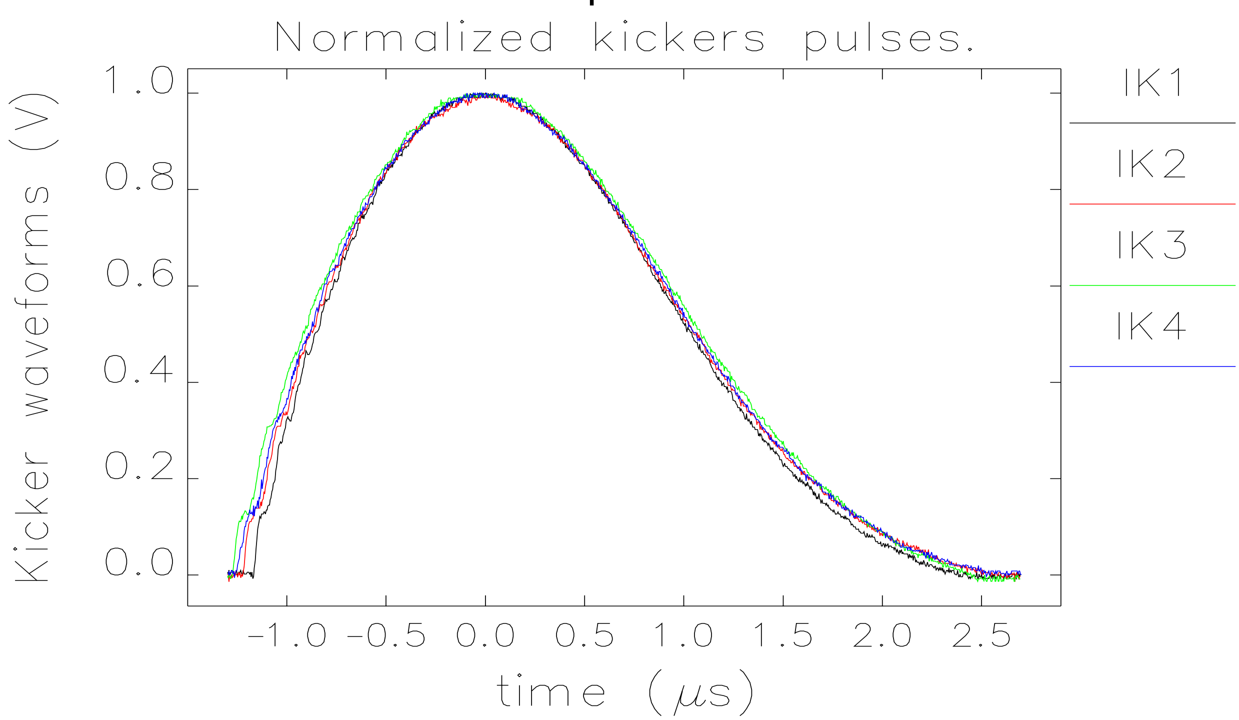
To remove injection transient

Thick septum leakage field orbit can be fixed by RT feedback in feedforward mode (software in development).

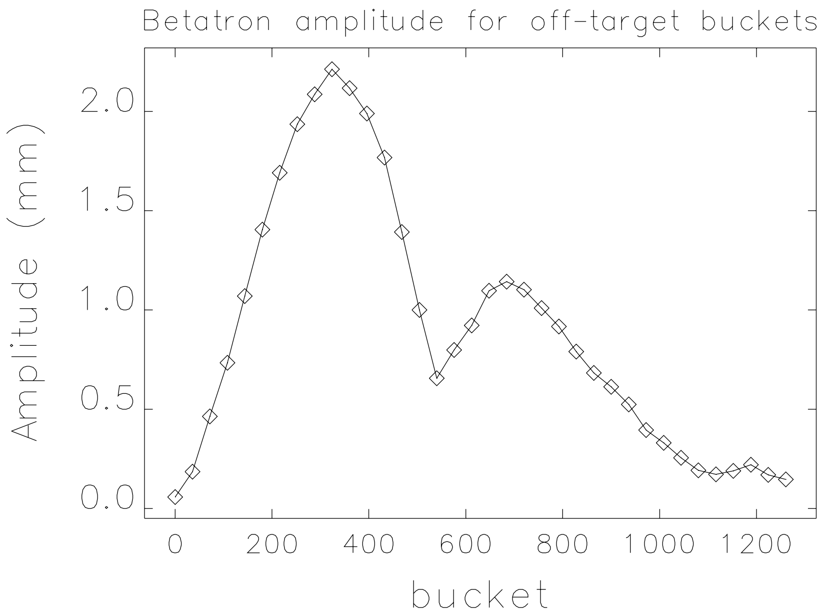
Matched kicker bump: Injection efficiency 75%-95% due to combination of large booster beam size and small horizontal SR aperture.

- Thin septum replacement (10/98) increased aperture by 1 mm.
- Thinner septum design (future). 1 mm goal.
- BTS matching adjustment (9/99).
- Temporary replacement of 2.5 mm x 15 mm ID3 VC with 4 mm x 20 mm will increase aperture (next shutdown 10/99).

Kicker pulse shape: different shapes due to variation in kicker PFNs causes emittance blow-up of other bunches.



.



- Need match of pulse shape to relatively high tolerance.
- Match in-tunnel cable length during (10/99) shutdown.
- Match other circuit parameters later.

Operation with reduced injection transient (soon)

Thick septum leakage field orbit fixed + matched kicker bump for target bunch.

Expect less SR beam emittance blow-up.

Commissioning

Radiation Dose Measurements

Injected beam losses on ID vacuum chambers will send brehmstrahlung photons down the beamline to scatter on beamline components.

Simulated top-up injection conditions using stored-beam dumps with open shutters gave a worst case of 12.5 rem/h when scaled to 40 nC/s.

Top-up injection measurements with 1 nC/s dumped at two different ID VCs produced a scaled worst case value of 0.25 rem/hr.

Estimated radiation dose is about 3 mrem/h for normal top-up operation assuming all of the injected beam is dumped at one location.

Commissioning (cont’d)

Top-up safety tracking test

The scenarios used in simulations cannot be tested as it would involve defeating interlocks and creating extreme magnet faults.

One aspect that could be tested: how severe of a dipole short is required to lose stored beam?

- Measurements gave a value of 5%.
- Simulations gave 9% and hence are conservative.

Top-up Operating Modes

High-current stability mode

Inject either on an as-needed basis or on a fixed time interval.

As-needed basis:

- Specify target current I_0 and incoming charge ΔQ. Stability is given by $\varepsilon \approx f_{rev}\Delta Q / I_0$.
- Injection occurs when current falls below target current
- Because of 10% injection variation, the injection occurs at irregular intervals
- With 0.04 nC we achieved a stability of 0.1 mA for 100 mA (10^{-4}). Injection interval was about 7 s.
- Unpredictable time of the injection event is undesirable to users

Fixed time interval

- Specify target current I_0, time interval T, and provide incoming charge corresponding to $\delta I > I_0 T / \tau$ where τ is the lifetime.
- At the end of each interval we inject only if $I < I_0$, giving a stability of $2\delta I$.

Top-up Operating Modes (cont'd)

Refill mode

Beam is allowed to decay undisturbed for several hours, then beam is injected with shutters open to reach the target current.

For example, in one hour the 100-mA beam decays by 3 to 5 mA. Refilling would take 8 to 12 seconds, giving 99.7% duty factor and low user impact.

Presently standard APS operation involves filling with shutters open to 100 mA every 12 hours.

Top-up Operation Issues

Bucket selection

Injector produces one bunch in one cycle.

Buckets injected are determined from list of weakest stored bunches to maintain punch pattern.

Operation concern on refill

Brehmsstrahlung propagates through small gap ID beamline, and scatters on aperture in first optics enclosure (FOE).

Integrated radiation is very small (about 100 μrad), but has significant rate (~5mrem/h of n) during short injection period.

Pause of injection sometimes necessary.

Need very small beam losses at ID3.

Sharing injector system

Develop rapid switching between SR injection and the low-energy undulator test line in support of a free-electron laser demonstration program.

Top-up Operation Issues (cont'd)

Injection timing jitter

We found no missed or skipped injection pulses in several hours of testing

The timing jitter was 60 ms in a one-hour measurement, consistent with the 60-Hz line frequency drift.

Post-beam dump diagnostics

Injection magnets will be activated very frequently during a store. Though kickers have been very reliable, they but will have to be questioned when beam is lost.

We plan to implement pulse histories for the injection pulsed magnets.