On-Axis Swap-Out Injection

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Outline

- Choice of emittance ratio
- Why inject on axis?
- Injector options
- Injector and pulsed magnet requirements
- Radiation issues
- Conclusion and questions

Choice of Emittance Ratio for USR

- Present-day rings run with emittance ratio κ~0.01
- For very low natural emittance, this is pointless
  - Intrinsic emittance from undulator is

$$\epsilon_r = \frac{\lambda}{2\pi}$$

  - Pointless to make either horizontal or vertical emittance significantly less than this
- For 10 keV photons, threshold is about 10 pm
- USR should be operated differently
  - Set emittance ratio κ~1 without harming brightness
    - Improvement due to small κ may be illusory owing to beam stability and beamline optics limitations
  - Reduces IBS and Touschek rates dramatically
  - "Round beams" is a frequent request from users

Injection Issues

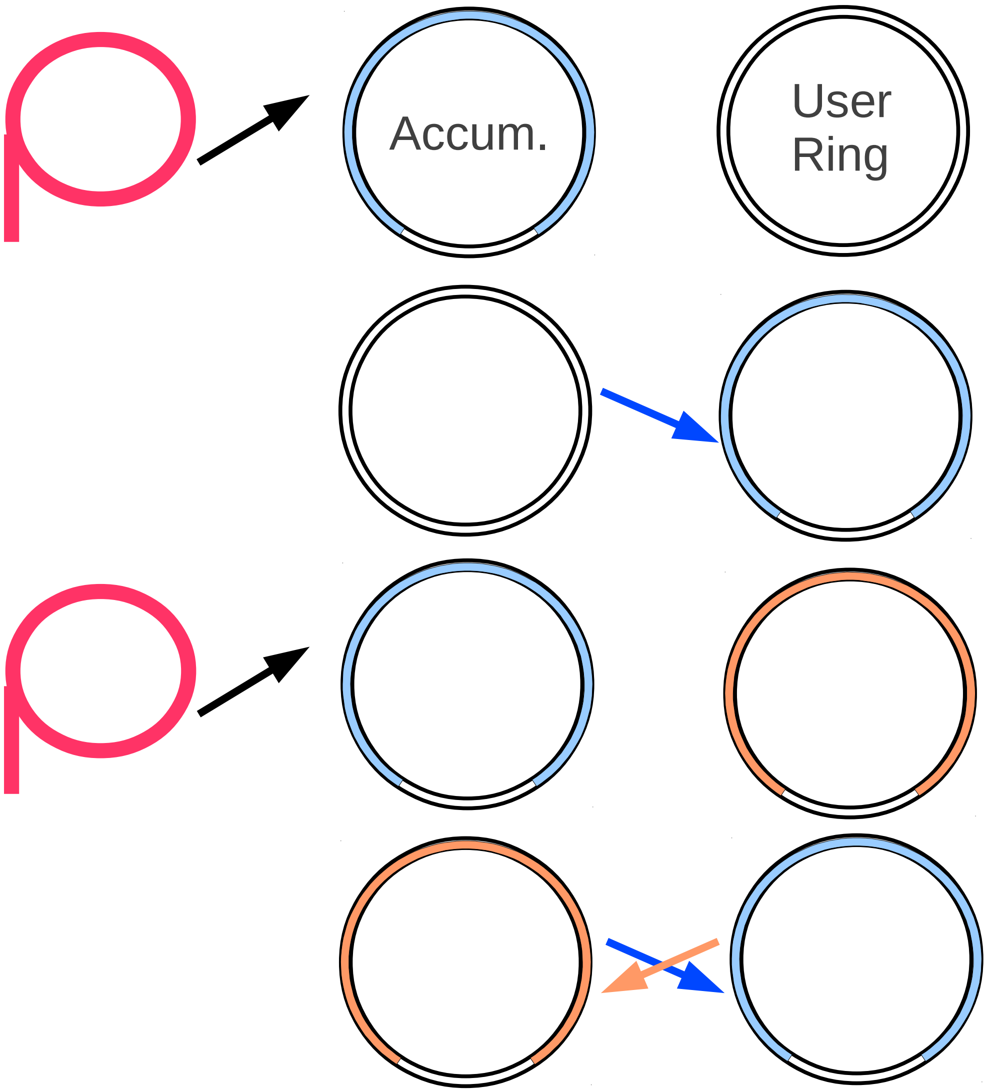
- All present-day ring light sources use beam accumulation
  - Each stored bunch/train is built up from several shots from the injector
  - Incoming beam has a large residual oscillation after injection
    - Requires typical horizontal DA of ~10 mm or more
  - In the presence of x-y coupling, residual oscillations result in loss on vertical small-gap chambers
    - Incompatible with large x-y coupling
  - Top-up doesn't help here because the injection efficiency is likely to be very low
- We proposed to use "swap-out" injection[1,2]
  - Kick out depleted bunch or bunch train
  - Simultaneously kick in fresh bunch or bunch train
- This was the operating mode of one of the first dedicated SR sources, TANTALUS[3]

[1]M. Borland, "Can APS Compete with the Next Generation?", APS Strategic Retreat, May 2002.
[2]L. Emery, M. Borland, "Possible Long-term Improvements to the APS," Proc. PAC 2003, 256-258 (2003)
[3]E. M. Rowe and F. E. Mills, Particle Accelerators **4**, 211 (1970).

ID Gap Benefit

- Present-day rings have insertion devices with relatively wide horizontal gaps
  - Necessary in order to preserve injection aperture
  - Prevents use of helical devices
  - Makes production of vertically- or elliptically-polarized radiation more difficult
- If injection is on-axis, this problem goes away
  - Can use round ID chambers
- See M. Jaski's talk for some implications

Swap-Out Concept Using an Accumulator[1,2]



Fill accumulator from linac/booster.

Transfer on-axis from accumulator to UR.

Fill accumulator, use top-up to maintain fill.

Swap beams when UR beam decays. Repeat from last step.

[1] M. Borland, "Can APS Compete with the Next Generation?", APS Strategic Retreat, May 2002.
[2] L. Emery, M. Borland, "Possible Long-term Improvements to the APS," Proc. PAC 2003, 256-258 (2003).

Discussion

- Accumulation ring (AR) and user ring (UR) would occupy the same tunnel to reduce cost
- AR design easier than UR design
  - No user straight sections
  - May have comparable emittance and still allow accumulation
- Need not swap the entire beam from ring-to-ring
  - Swapping a fraction of the beam reduces transients seen by users and AR/UR systems
  - Would require increased swapping frequency
  - Would reduce need for a long kicker flat-top.

Low-Emittance Booster Injector

- A large-circumference booster emittance can be close to that of the ring (e.g., SLS booster)
  - Optics is “easy” since there are no user straights
  - Can occupy the same tunnel as the user ring to reduce cost
  - Can fill bunch trains at few Hz repetition rates
- This has advantages over accumulator concept
  - Booster emittance can be lower since we needn't accumulate in it (inject on axis)
  - Less costly overall since accumulator still needs booster to fill it
- Could also flat-top the booster ramp and transfer individual bunches using very fast (e.g., ILC-like) kickers.

Full-Energy Linac Injector

- In principle, could swap-out the whole ring or replace trains
- Probably not the optimum choice
  - 9 GeV emittance would be ~30 pm for typical ~0.5 nC bunches
    - Probably can do better with in-tunnel booster
  - Short bunches may be a problem
    - Collective effects may accentuate beam-quality blip
  - Long linac requires costly separate tunnel
  - Linac structures, rf systems more costly and less reliable than booster
- However
  - Might use linac to provide short, low-charge pulses for a few turns
  - The linac could also drive an FEL in its spare time

Example for 9 GeV τUSR

- For 200 mA and 0.5 nC/bunch, need ~8300 bunches
  - 500 MHz rf, fill 80% of 10360 buckets
  - 4.1 μs of 20.7 μs revolution time available for kicker rise/fall
  - If $T_{rise} = T_{fall} = 10$ ns, need N_T=202 trains of 41 bunches
  - Kicker flat-top is 82 ns long
- Fractional droop of bunch train current between replacements is

$$D \approx \Delta T_{inj} N_T / \tau$$

- Assuming τ=2 h and D=0.1, need $\Delta T_{inj} = 3.6$ s
  - Variation in total current is 0.05% pk-pk
- Inject 41 bunches of 0.5 nC each time
  - Average injector current of 6 nA
  - Average beam power of 50 W
  - This isn’t challenging

Pulsed Magnet Requirements

- Ideally, want injector emittance to be the same as ring emittance
  - Reduces brightness transient after injection
- Pulsed magnet stability affects emittance dilution[1]

$$\Delta\epsilon_x = \frac{1}{2}\beta_x \Delta x'^2$$

- For τUSR, have

$$\epsilon_x = 4pm \qquad \beta_{inj} = 90m$$

- For 10% dilution need 100 nrad stability and flatness
- For a 1 mrad kicker, we *might* get 1 urad
  - Implies the emittance is ~50 pm after decoherence
- Conclusion:
  - Need not try so hard for low injector emittance
  - Low beta functions at injection might be better
  - Best to inject bunch trains rather than swap entire fill, so as to reduce brightness transient

1: D. Edwards, M. Syphers, An Introduction to the Physics of High Energy Accelerators, Wiley (1993).

Radiation Load

- Radiation from extracted trains is small
  - Again, only about 50 W
  - No problem to design a dump for this
  - Presumably dump would be internal to the ring
- Radiation load from 2 hour lifetime is more worrisome
  - ~5 W average power
  - For APS, have only 0.15 W but see radiation damage to PM undulators
    - Can be mitigated with better material choice
  - Collimation for Touschek losses is presumably straightforward
  - Can we intercept gas-scattered electrons without cutting into acceptance?

Conclusion

- Swap-out injection has many advantages
  - Allows κ~1, which dramatically mitigates IBS and Touschek
  - Makes round beams for users
  - Makes best use of the small emittance
  - Allows using round chambers in IDs for more flexible device design
  - Allows pushing the natural emittance to lower values
- Injector requirements do not seem difficult
  - Top-up experience shows that injector reliability can be >97% (APS value)
- Questions:
  - Can required kickers be built? (fast rise/fall, long flat top, high stability/flatness)
  - Is a ~50 pm booster emittance practical?
  - Can the booster damping times be sufficiently short?
  - Can we control the location of the beam losses?