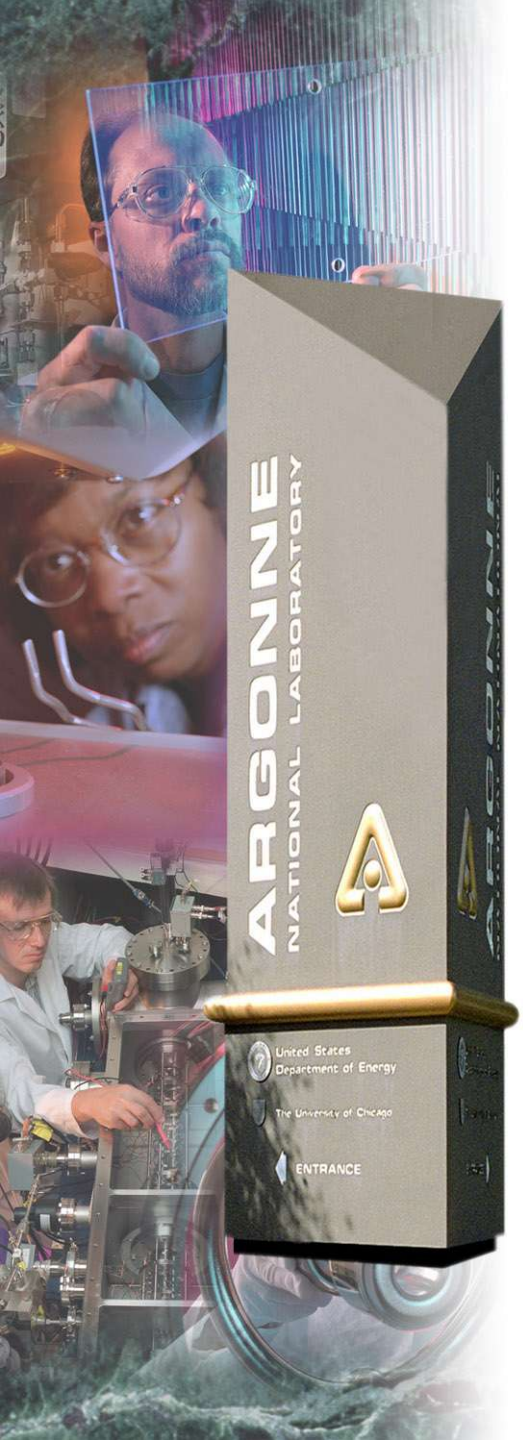


APS Storage Ring Improvements and Research

Louis Emery

Argonne National Laboratory

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Office of Science
U.S. Department of Energy

Outline

- **OAG Impact on brightness, orbit stability and reliability.**
- **Ongoing projects continuing the above**
- **SR manager's function**

OAG's Impact on APS Performance

- **Three figures of merit for light sources, which can be improved with physicist's effort and software developments**
- **Higher photon brightness**
  - Lower emittance optics implementation
  - Control over y/x emittance ratio
- **Orbit (and photon beam) stability**
  - Topup injection implementation
  - Faster DC orbit correction
  - CPU correction
- **Reliability**
  - Fault (i.e. beam dump) analysis
  - Automatic tuning tools

Higher Photon Brightness

- **On-axis brightness increases with current, small beam size and undulator design.**

$$B \propto \frac{I}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$ where, for example, $\Sigma_x^2 = \sigma_x^2 + \sigma_r^2$

- **Higher stored current (i.e. higher flux)**
  - Need to ensure all beamlines and users have hardware compatible with higher flux
- **Longer or optimized undulators**
  - Need large effort to design new hardware
- **Lower emittance (same flux)**
  - Can be reduced by physicists using no extra hardware

Lower Emittance Lattice

- **Original emittance: 8 nm-rad**
- **Introduce dispersion in straight section: 4.4 nm-rad**
- **Optimize effective emittance: 3.1 nm-rad**
  - One cell was optimized (Borland), then the whole ring was matched with two types of cells, and then implemented
  - Optics characterized (emittance, lifetime, injection, nonlinear aspects)
  - Optics perturbations corrected to recover lifetime (Sajaev, APG)
- **Linear optics perturbations are corrected with SVD method that I pioneered. Sajaev later provided a faster way of measuring optics perturbations.**
- **Nonlinear aspect of optics (i.e. sextupole magnet settings) optimized empirically to maximize lifetime**

Lattice Optics Correction

- **Non-ideal optics reduces lifetime through enhancing the nonlinear effect of sextupoles. Optics correction reduces or undoes this enhancement.**
- **Use matrix-based method analogous to orbit correction (i.e. correction without finding the exact sources of error)**
  - Multiply vector of measured values with a pre-determined matrix to get vector of corrections
  - Input values are results of individual experiments, which are automated; correctors are quadrupole settings
  - Need to convert problem into a linear one, e.g. use $\Delta\beta/\beta$ instead of $\Delta\beta$
- **Correction matrix is calculated with singular value decomposition with an appropriate number of singular values for stability.**

Y/X Emittance Ratio

- **Low vertical emittance increases brightness (good), but reduces lifetime (bad). Need control for the compromise.**
- **How best to increase vertical emittance if we need to?**
- **Recognize two physical contributions in general and apply different adjustment for each**
  - Coupling between x and y motion (bad for injection) → Harmonic-combination "knobs" for minimization
  - Vertical dispersion (similar to horizontal emittance) → Matrix-based correction method for zeroing vertical dispersion
- **Control lifetime through vertical dispersion only → no increase in radiation damage through injection losses**
- **Use configurable optimizer tool for coupling and feedback tool on Y/X emittance ratio readback**

Top-up Implementation

- **Constant current → Stability of Xray optics.**
- **Less dependence on lifetime → Allows lower emittance optics, special bunch patterns**
- **Safety of injection with open shutters**
  - "Possibility" of transporting 7 GeV electron beam outside tunnel by "some" magnet faults
- **Safety tracking (Borland and Emery)**
  - Thousands of magnet fault scenarios were identified, automatically generated, and simulated to show that the interlocks to be used were safe.
- **Specified alignment of apertures assumed in tracking, alignment procedures, lower limit in operating energy for SR**

Top-up Implementation (cont'd)

- **Specified programming of injection timing computer (ASD-CTL)**
  - Allow setting of target current, top-up injection interval, various warning signals for flexibility of operation
- **High-level software (OAG)**
  - Preservation of any arbitrary set bunch pattern
    - Coordination of injector beam turn-on and data processing for bucket selection of “weakest” bunch
  - Reduction of radiation exposure of SR components
    - Injector pre-pulses reduced when booster septum thermal transient corrected with feedforward

Facets of DC Orbit Correction

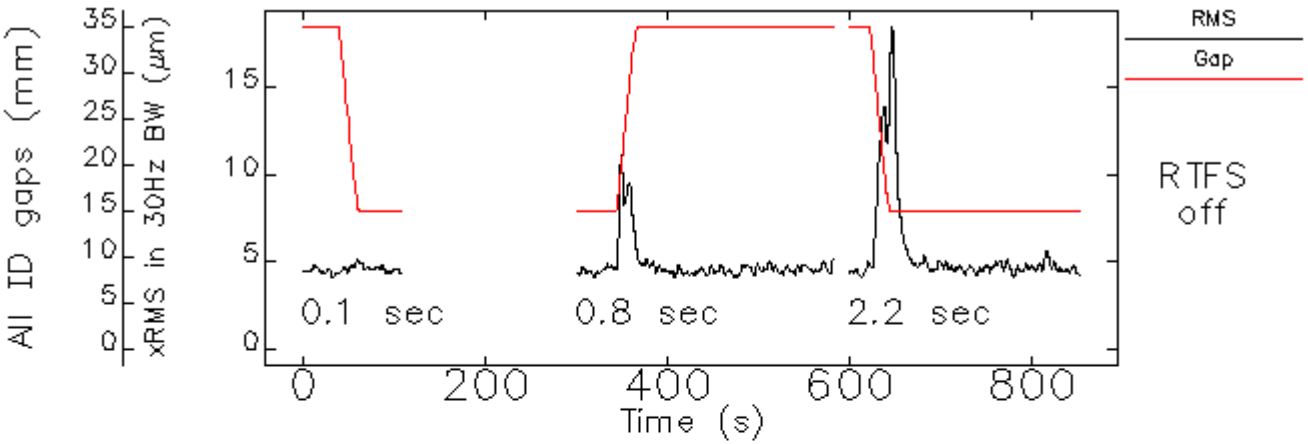
- **Algorithms (SVD, local steering, circumference compensation, weights, interaction with fast feedback system)**
- **Data organization (BPM offsets, setpoints, errors, averaging, archived configurations)**
- **Robustness (tests, limits, despiking, alarms)**
- **External application (configuration GUIs, compensations for intensity and ID gap settings)**
- **Hardware (stabler BPMs, Xray BPMs)**

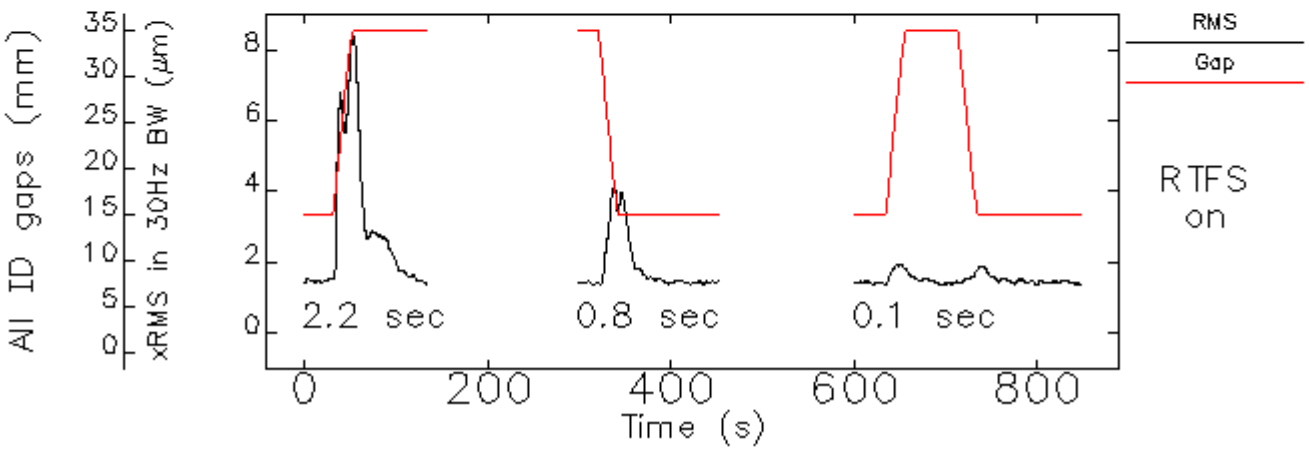
Faster DC Orbit Correction

- **Goal: reduce short-term transients.**
- **Culmination of 2 years of CTL and OAG efforts**
  - Workstation-based and standard links to correctors: 2 s
  - Workstation-based and faster links to correctors: 0.5 s
  - Local computer-based and RTFS links: 0.05 s
- **Use a local computer connected to the RTFS system**
- **All functionality preserved for global correction and local steering (e.g. all BPMs and correctors available)**
- **Old systems still available as fall-back**
- **1.3 Hz BW reduces transients due to ID gap opening and closing**

Faster Orbit Correction (cont'd)

Effect of correction interval on beam motion from all gaps moving





CPU Transient Correction

- **Circularly polarized undulator (CPU) produces either RCP or LCP with "hard" switching.**
- **Orbit transient of 200 um occurs for about 40 ms**
  - Transient depends on coil current and direction of polarity switch
- **Hardware applies a waveform program to two pairs of small dipole corrector coils and other multipole correction magnets**
- **Organized data system for waveforms and DC correction values for various operating conditions: corrector channel, main current, polarization switch direction, time index.**

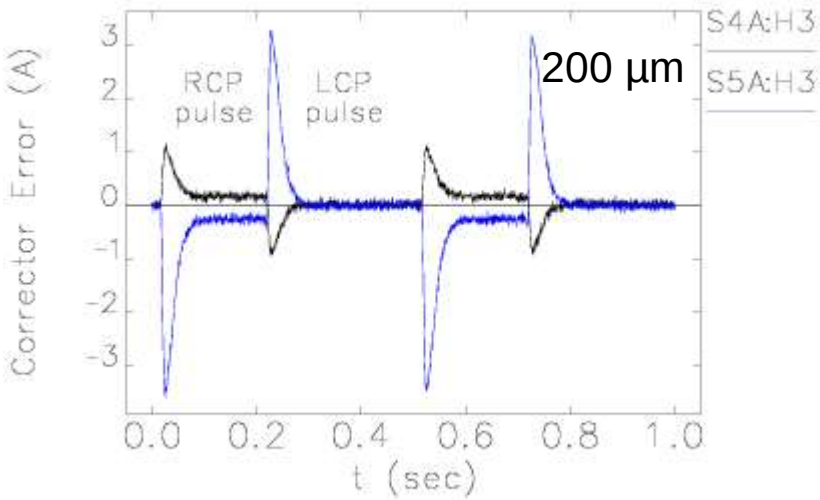
CPU Transient Correction (cont'd)

- **Magnetic measurement data for dipole corrections found to be useless after installation**
- **Used measured beam perturbation to determine program to dipole correctors using mathematical inversion at first, then a more manual approach.**
- **Final result is a short 7 um perturbation at each polarity switch**

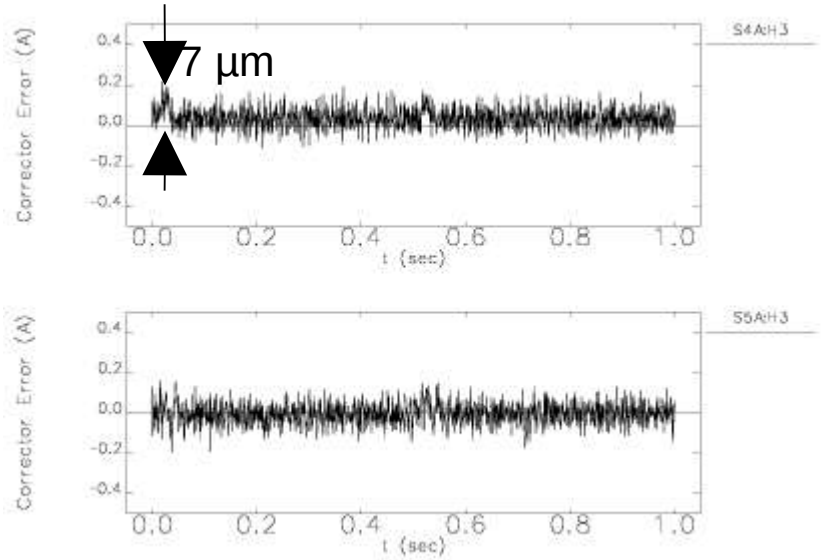
CPU Transient Correction (cont'd)

Orbit Perturbations as Seen by RTFS Signals

Uncorrected



Corrected



Fault Analysis Tools

- **Fault analysis helps guides repairs**
  - Results in improved reliability and availability
- **Beam dumps occur from beam motion or from bad inputs to interlocks**
- **OAG collects various data (BPMs, correctors, other hardware) at various time resolution(μs to s)**
- **Learned signatures of known causes for comparison**
- **Mysterious faults are examined by OPS and OAG**
  - New faults may require modification of logging for better diagnosis
  - Reoccuring faults that are very rare may require many man-hours of investigations, which may appear out of scale compared to down time, but is necessary.

Automatic Tuning Tools

- **Experienced physicists can make accelerator adjustments by hand**
  - Packaged expertise into software available to many
- **Created general software that is easily configurable**
  - SR y/x emittance ratio (lifetime control)
  - SR injection efficiency (reduces beam losses which cause damage to IDs)
    - on-axis and off-axis injection
    - booster-to-SR rf phase
  - Transport line trajectory control
  - Stabilizing pulsed magnet out against thermal effects

Ongoing Projects with Impact on Source Brightness and Stability

- **In multi-group efforts, OAG leads optics simulations, integration of systems, and operational implementation**
- **Extended straight section (for multiple undulators)**
  - Initial work (Borland) on laptop at workshop
  - With Sajaev of APG, determined beam dynamics-related limitations of selected cases of cell shortening
  - Determined physical aperture limitations
- **Including Xray BPMs in RTFS (improvement of orbit stability in 1 Hz - 60 Hz range)**
  - Organize calibration data in RTFS software, check stability

Ongoing Projects with Impact on Source Brightness and Stability

- **Off-momentum optics for even lower emittance**
  - One version has run during studies in top-up mode
  - Effective emittance is 2.5 nm-rad (compared to 3.1 nm-rad for present optics)
  - Displaced ID photon beam compensated with an angle
  - Lower lifetime expected and observed
- **Canted undulator**
  - Steering ability preserved for two undulator beams
  - Calculated shielding of shutters

What it Means to Be SR Manager

- **Operations**
  - Set up magnet configurations for user operations
  - Make sure various aspects of the optics and orbit correction are implemented
  - Specify (or write) software procedures for operations
  - Analyze operational problems such as beam dumps, instabilities, emittance growth and orbit divergence
  - Make a schedule of SR machine studies (presently delegated)

What It Means to Be SR Manager

- **List of improvements with priorities**
- **Technical oversight of SR improvements**
  - Making sure that subsystems are integrated with the rest
    - Topup operations, faster DC orbit correction, injection section replacement
  - Develop new capabilities for the APS
    - Higher brightness through lower emittance or customized beta function
    - Improved operability through higher lifetime from optics optimization