SPEAR 3: Operations Update and Impact of Top-Off Injection

R. Hettel for the SSRL ASD

2005 SSRL Users’ Meeting
October 18, 2005
SPEAR 3 Operations Update and Development Plans

- Highlights of 2005 SPEAR 3 user run
- Machine performance
- Accelerator development plans
- Timing modes and short bunches
- 500 mA operation
- Top-off operation possibilities
**SPEAR 3 Safety Stand-down and Restart Validation**

Sept 04: SPEAR start-up for user run to begin Oct 18

Oct 11: Type A electrical accident at SLAC

Oct 12: Accelerators shut down

Oct 12 - Jan: Staff training and preparations for restart (e.g. circuit breaker analysis, safety procedure revisions, etc)

Jan 10-13: Restart validation review

Jan 18: SSRL accelerator restart

Feb 3: First beam lines opened
2005 User Run Highlights

- 95.0% user beam uptime
2005 User Run Highlights – cont.

- First 500 mA operation – June 20, 2005
2005 SPEAR3 Performance – Lifetime

• ~60 h lifetime @ 100 mA
  - ~0.1% horizontal-vertical coupling ⇒ ~10-20 µm vertical beam size
    ⇒ lifetime could be greater if coupling increased
  - reduced lifetime when BL5 EPU in intermediate state
    ⇒ reason undetermined; will resume study with new BL5 vacuum chamber in 2006
2005 SPEAR3 Performance – Orbit Stability

- Slow orbit feedback
  - ~0.2 µm orbit motion
  - “glitches”: ID gap changes, trestle traffic
2005 SPEAR3 Orbit Stability - cont.

- BPM processor temperature dependence
  - adding photon BPMs to feedback
  - adding air conditioning for BPM electronics in 2006
SPEAR 3 Circumference Changes - RF Frequency Feedback

- RF frequency (green) changes by 1 kHz for a 2°C tunnel temperature variation (red) over 1 month period.

- RF frequency (green) changes ~30 Hz twice daily from lunar tide (9°C pk-pk outside diurnal temperature over 4 days shown in violet).
Floor Alignment Monument Elevation Changes

-0.00040
-0.00030
-0.00020
-0.00010
0.00000
0.00010
0.00020
0.00030
0.00040

400 µm

June 2003 - July 2003
Nov 2003 - July 2003
Sep 2004 - July 2003

R. Hettel                SPEAR 3 Update and Impact of Top-Off               SSRL Users' Meeting              Oct. 18, 2005
Floor Motion Study - Hydrostatic Level System
(G. Gassner - SLAC)

- Tunnel floor moves diurnally and seasonally
- HLS to be extended in tunnel and onto experimental floor
**Orbit Stability in 1-200 Hz BW**

BPMx(7,6) POWER SPECTRUM (4000 points)

- **BPMx PSD [μm²/Hz]**
- **Frequency [Hz]**

- **xrms = 3.7 μm**

BPMy(7,5) POWER SPECTRUM (4000 points)

- **BPMy PSD [μm²/Hz]**
- **Frequency [Hz]**

- **yrms = 2.2 μm**

**red = noise floor**

BPMx(7,6) Integrated PSD (RMS=3.7 μm)

- **Mean Square Displacement [μm²]**
- **Frequency [Hz]**

BPMy(7,6) Integrated PSD (RMS=2.2 μm)

- **Mean Square Displacement [μm²]**
- **Frequency [Hz]**

---

R. Hettel  SPEAR 3 Update and Impact of Top-Off  SSRL Users' Meeting  Oct. 18, 2005
**Orbit Stability in 1-200 Hz BW - Photon BPMs**

- photon BPM noise spectra for different beam lines vary
  - beam line monitor systems introduce additional noise
  - photon BPM performance must be characterized and understood before adding to feedback

---

R. Hettel  SPEAR 3 Update and Impact of Top-Off  SSRL Users' Meeting  Oct. 18, 2005
SPEAR 3 Development – Orbit Monitoring and Stability

• Turn-turn digital BPM processing

- non-linear beam dynamics

• More BPMs for BL 12

• "Fast" orbit feedback (<50 Hz)

• Air conditioned BPM processing stations

• HLS system for motion studies of floor, accelerator and beam line components
**SPEAR 3 Development – SLM and Pinhole Camera**

- UV/visible synchrotron light monitor: Jan 2006
  - transverse beam size, emittance and bunch length measurements
  - bunch-bunch stability studies

- Improvements to X-ray pinhole camera (BL 2)

![X-ray pinhole image](image)

X-ray pinhole image

50 X 150 µm RMS

@ 1% coupling

0.1% coupling expected
**SPEAR3 Development** -
**Double-Waist Chicane Optics (BL 12, BL 13)**

- BL12 in-vac undulator
  - ~5.5 mm gap
  - 7.6 meters
  - 4.8 m matching straight
  - 3 m standard straight

- BL13 EPU
  - 10 mm gap

---

R. Hettel  SPEAR 3 Update and Impact of Top-Off  SSRL Users' Meeting  Oct. 18, 2005
Double-Waist Chicane
Double-Waist Chicane Optics
Tracking and Frequency Map Analysis with IDs
Double-Waist Chicane Optics Commissioning

• FY 2006
  ➢ install quadrupole triplet and temporary beam chamber, no chicane
  ➢ install new power supplies to allow independent control of matching straight section quads and triplet
  ➢ commission, characterize and optimize chicane optics with beam

• FY 2007
  ➢ install chicane magnets, chicane vacuum chambers, BL 12, in-vacuum undulator
  ➢ install additional quadrupole and chicane magnet power supplies
  ➢ commission, characterize optimize chicane lattice with undulator
SPEAR 3 Development – Timing Mode Studies

- Normal fill:
  - 279 bunches
  - 0.36 mA/bunch/100 mA
  - 586 ns
  - 195 ns
  - 781 ns

- "Camshaft" fill:
  - 100 ns
  - 100 ns
  - 5-20 mA
  - 4-7 bunches fill
  - 140 mA max, ~2 h lifetime
  - Unless increase vert beam size

- ~20 mA/bunch
  - # bunches limited by HOM heating in chamber bellows

R. Hettel  SPEAR 3 Update and Impact of Top-Off  SSRL Users' Meeting  Oct. 18, 2005
SPEAR 3 Timing Mode Studies - cont.

• Tested timing fill patterns at 100 mA:
  ➢ ~25 mA/bunch maximum
  ➢ 7 or more 20 mA bunches; lifetime = 2 hours without increasing vertical beam size
  ➢ Camshaft bunch lifetime = (50, 6, 2) hours for (0.36, 5, 20) mA camshaft bunch

• Bunch purity: need $10^{-6}$?
SPEAR 3 Bunch Length Reduction?

• Nominal bunch length = 17 ps rms (5 mm) @ 1mA/bunch

• Bunch length increases with current/bunch:

![Graph showing bunch lengthening and energy widening vs current (mA)](image)
**SPEAR 3 Bunch Length Reduction? - cont.**

- **Equilibrium short bunch schemes:**
  - Low momentum compaction lattice
    - need to calculate attainable bunch length
    - probably low current
  - Harmonic RF cavity
    - factor of ~2 decrease
    - expensive

- **Non-equilibrium manipulations** (not likely to be implemented):
  - Transient RF phase modulation (on for few msec, off for few 10s msec)
  - Transverse kick with betatron oscillations (similar transient to above) - W. Guo
  - Transverse zero-cross kick + unkick (very expensive) - S. Zholents
SPEAR 3 500 mA Operation

• First 500 mA - June 20, 2005
• BL6 opened with 500 mA - July 19
• No serious chamber heating
• Lifetime = 14 hours at 500 mA, IDs closed

• Multi-bunch stability achieved
  ➢ RF feedback loops tuned to damp longitudinal instabilities
  ➢ Sextupole magnet strengths increased to damp transverse instabilities (13% lifetime hit)
  ➢ Some ion instabilities observed
  ➢ No immediate need for multi-bunch feedback
**SPEAR 3 500 mA Operation - Fill Scenarios**

Assume fill rate = 50-60 mA/min (after injector improvements), 7 A-h VQ
SPEAR 3 500 mA Operation - Top-Off Injection

- Inject with beam line stoppers open
  - Reduce thermal transient on beam line optics to improve stability
  - Choose optimum beam delivery time (hours to seconds)
- Maintain high beam current constancy
SPEAR 3 Top-Off Injection - Issues

• Radiation safety
  ➢ other labs successful in injecting with BL stoppers open
  ➢ existing BL shielding sufficient?
  ➢ existing SPEAR and Injector shielding sufficient for higher average current?

• Efficient injector and injection into SPEAR
  ➢ improvements to gun, linac and booster stability, reliability
  ➢ improvements to BTS injection line
**SPEAR 3 Top-Off Injection Issues for Users**

- Interruption to user experiment and data acquisition
  - What is desired current constancy? (30%? 10%? 1%? 0.1% other?)
  - What is tolerable fill interruption time?
    - depends on current constancy factor and charge/shot from injector
    - charge/shot for single bunch may be limited to 10-20% of bunch current to avoid detector and other component transients?
    - bunch train filling only possible with new booster RF system
  - What is tolerable minimum beam delivery time?
    - depends on current constancy factor and beam lifetime
    - lifetime can be increased with vertical beam size and/or bunch length
  - Can user data acquisition be gated, synchronized or filtered to avoid injection transient effects?

![injection kicker transient graph]

injection kicker transient = ~10 ms

(~0.1 ms with feedback)
**Top-Off Injection at Other Labs**

- **APS**
  - inject every 120 sec, single bunch (0.5 mA/shot; accumulator ring)
  - 0.5% current stability (lifetime = 7 h @ 100 mA)

- **SPring-8**
  - inject every 1-5 min
  - 0.1% current stability (lifetime = 27 h @ 100 mA)

- **ESRF**
  - no top-off; inject with shutters open
  - lifetime = 75 h @ 200 mA (9 h @ 90 mA, 16-bunch)

- **SLS**
  - inject every 2-4 min (0.1-0.5 mA/shot, single bunch)
  - 0.1% current stability (lifetime = 3-4 h @ 400 mA)

- **ALS (planned)**
  - inject every 30 sec, train of 10 bunches (1.5 mA/shot)
  - 0.3% current stability (lifetime = 3 h @ 500 mA)
  - 5 M$
SPEAR 3 Top-Off Injection - Plan

• FY 2006
  ➢ Continue injector studies to improve reliability, reproducibility and fill rate
  ➢ Rebuild BTS transport line to remove several vacuum windows
  ➢ Conduct radiation safety study for injection with beam line stoppers open
  ➢ Plan (and conduct) tests of injection transients on beam line data acquisition
  ➢ Work with users to identify top-off issues and tolerable modes

• FY 2007
  ➢ Inject with beam line stoppers open (delivery time = hours)
  ➢ Define current constancy goal and acceptable user interruption period and frequency
  ➢ Continue injector development to achieve top-off goals

• FY 2008 ….
  ➢ Implement accelerator upgrades to achieve top-off goals
**SPEAR 3 - Summary of Plans for 2006**

- Improve orbit stability
  - faster orbit feedback
  - more BPMs, air-conditioned BPM processors
  - HLS
    - machine and beam line component stability studies (Noise Abatement Team)
- Commission and characterize double-waist chicane optics
- Commission UV/Visible SLM and measure bunch parameters
- Conduct beam dynamics studies for BL 12 and BL 13 EPU
- Carry out top-off study plan
- Continue injector improvements (including rebuild BTS)
- Strive to deliver the best beam possible to users