Electron Cloud Issues for the Advanced Photon Source Superconducting Undulator

Katherine Harkay
Electron Cloud Workshop, Cornell, Oct. 8-12, 2010

Acknowledgements:
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Introduction

- Advanced Photon Source (APS) a 7-GeV electron synchrotron light source
- APS Upgrade CD0 approved summer 2010
- Development of a superconducting undulator (SCU) part of the upgrade
- Possible electron cloud effects for electron beams
  - Studies at APS and CesrTA
  - ANKA experience with high heat loads in SC insertion device
  - Electron cloud models appear incomplete for electron beams
- Detailed heat load analysis undertaken, conservative assumptions for beam-induced heat load
- Preliminary thoughts on electron cloud mitigation strategies for APS SCU
Outline

- APS superconducting undulator
- Case for improved photoelectron model
- Strategies for EC mitigation
- Summary
## Superconducting undulators in the APS upgrade program

### SCU Road Map

<table>
<thead>
<tr>
<th>Year</th>
<th>SCU1 (1.6-cm, 2m-long, 2m-cryostat)</th>
<th>SCU2 (1.6-cm, 2m-long, 3m-cryostat)</th>
<th>SCU3 (?-cm, 2m-long, 3m-cryostat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>R&amp;D on SCU0 (1.6-cm, 42-pole, 2m-cryostat)</td>
<td>Critical issues R&amp;D: *</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
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<td></td>
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<tr>
<td>2013</td>
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<td></td>
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<tr>
<td>2014</td>
<td></td>
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<td></td>
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<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* provided additional staff is available

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Y. Ivanyushenkov, Workshop on superconducting undulators, APS, September 20-21, 2010
First two superconducting undulators for the APS

- APS superconducting undulator specifications

<table>
<thead>
<tr>
<th></th>
<th>SCU0</th>
<th>SCU1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon energy at 1\textsuperscript{st} harmonic</td>
<td>20-25 keV</td>
<td>20-25 keV</td>
</tr>
<tr>
<td>Undulator period</td>
<td>16 mm</td>
<td>16 mm</td>
</tr>
<tr>
<td>Magnetic length</td>
<td>0.33 m</td>
<td>1.15 m</td>
</tr>
<tr>
<td>Cryostat length</td>
<td>$\approx 2.0$ m</td>
<td>$\approx 2.0$ m</td>
</tr>
<tr>
<td>Beam stay-clear dimensions</td>
<td>7.0 mm vertical $\times$ 36 mm horizontal</td>
<td>7.0 mm vertical $\times$ 36 mm horizontal</td>
</tr>
<tr>
<td>Magnetic gap</td>
<td>9.5 mm</td>
<td>9.5 mm</td>
</tr>
</tbody>
</table>
Expected performance of SCU0 and SCU1

- Tuning curves for odd harmonics for two planar 1.6-cm-period NbTi superconducting undulators (42 poles, 0.34 m long and 144 poles, 1.2 m long) versus the planar NdFeB permanent magnet hybrid undulator A (144 poles, 3.3 cm period and 2.4 m long). Reductions due to magnetic field error were applied the same to all undulators (estimated from one measured undulator A at the APS). The tuning curve ranges were conservatively estimated for the SCUs.

- The minimum energies are 3.2 keV for the UA and 18.6 keV for the SCUs.

- The short 42-pole 1.6-cm-period SCU surpasses undulator A at ~ 60 keV and ~ 95 keV. The 144-pole SCU brilliance exceeds that of undulator A by factors of 1.8 at 20 keV, 7.0 at 60 keV, and 8.2 at 95 keV.

Y. Ivanyushenkov, Workshop on superconducting undulators, APS, September 20-21, 2010
## SCU0 Project Status and Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Status and Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial R&amp;D phase</td>
<td>Complete</td>
</tr>
<tr>
<td>Conceptual design</td>
<td>Complete</td>
</tr>
<tr>
<td>Conceptual design review</td>
<td>Passed in February, 2010</td>
</tr>
<tr>
<td>Detail design</td>
<td>In progress</td>
</tr>
<tr>
<td>Cryostat pressure safety review</td>
<td>Passed in July, 2010</td>
</tr>
<tr>
<td>Cryostat production review</td>
<td>September 2010</td>
</tr>
<tr>
<td>Cryostat manufacture</td>
<td>November 2010 – Spring 2011</td>
</tr>
<tr>
<td>Undulator assembly</td>
<td>Summer 2011</td>
</tr>
<tr>
<td>Measurement system design and manufacture</td>
<td>Summer 2010 – Summer 2011</td>
</tr>
<tr>
<td>Undulator tests</td>
<td>Fall 2011</td>
</tr>
<tr>
<td>SCU installation into the ring</td>
<td>Winter 2011-12</td>
</tr>
<tr>
<td>SCU beam test</td>
<td>Spring 2012</td>
</tr>
</tbody>
</table>
SCU cooling scheme

More details in the talk by John Pfotenhauer this afternoon.

Y. Ivanyushenkov, Workshop on superconducting undulators, APS, September 20-21, 2010
Experience at ANKA: SCU14 demonstrator

Beam heat load studies

Performance limited by too high beam heat load: beam heat load observed cannot be explained by synchrotron radiation from upstream bending and resistive wall heating. S. C. et al., PRSTAB2007

Pressure rise can be explained by including in eq. of gas dynamic balance electron multipacting. S. C. et al., PRSTAB2010

Possible beam heat load source: electron bombardment of the wall, beam dynamics under study

Sara Casalbuoni, ECLOUD10, Cornell, xx.10.10
# Heat loads and cooling system concept

<table>
<thead>
<tr>
<th>Heat source</th>
<th>Heat load @ 4K, W</th>
<th>Heat load @ 20K, W</th>
<th>Heat Load @ 60 K, W</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam</strong></td>
<td></td>
<td>6.6 (nominal)</td>
<td></td>
</tr>
<tr>
<td>Radiation</td>
<td>0.0116</td>
<td>1.21</td>
<td>4.2</td>
</tr>
<tr>
<td>Conduction through:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>beam chamber bellows</td>
<td>0.08</td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>beam chamber supports</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>He vent bellows</td>
<td>0.006</td>
<td>0.07</td>
<td>0.9</td>
</tr>
<tr>
<td>He fill pipe</td>
<td>0.012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cold mass support</td>
<td>0.005</td>
<td>1.2</td>
<td>5.6</td>
</tr>
<tr>
<td>radiation shields supports</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current leads at:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I = 0 A</td>
<td>0</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>I = 100 A</td>
<td>0.12</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>I = 500 A</td>
<td>0.45</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>Total at I = 500 A:</td>
<td>0.685</td>
<td>up to 45</td>
<td>86.1</td>
</tr>
</tbody>
</table>

**Conceptual points:**
- Thermally insulate beam chamber from the rest of the system.
- Cool the beam chamber separately from the superconducting coils.

In this approach beam heats the beam chamber but not the SC coils!

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Y. Ivanyushenkov, Workshop on superconducting undulators, APS, September 20-21, 2010
Cooling system - SCU dynamic heat load

- Task for cooling system is to keep the temperature of superconductor in the range 4.2-6K by intercepting both static and dynamic heat loads in the undulator system.
- **Dynamic heat load**

<table>
<thead>
<tr>
<th>Heat source</th>
<th>Heat load on 2-m long beam chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image current</td>
<td>2.44 W @ 100 mA [1]</td>
</tr>
<tr>
<td></td>
<td>(4.88 W @ 200 mA) [1]</td>
</tr>
<tr>
<td>Synchrotron radiation from upstream magnets</td>
<td>≈ 0.1 W (for wide chamber) [1]</td>
</tr>
<tr>
<td></td>
<td>(40 W for narrow chamber)</td>
</tr>
<tr>
<td>Electron cloud</td>
<td>2 W [1][3]</td>
</tr>
<tr>
<td>Wakefield heating in the beam chamber transition</td>
<td>0.093 W [1]</td>
</tr>
<tr>
<td>Injection losses</td>
<td>40 W (accident) [2]</td>
</tr>
<tr>
<td></td>
<td>2 W (non top up mode) [2]</td>
</tr>
<tr>
<td></td>
<td>0.1 W (normal top up mode) [2]</td>
</tr>
<tr>
<td>Max heat load:</td>
<td>≈ 45 W (injection accident)</td>
</tr>
<tr>
<td></td>
<td>≈ 6.6 W (non top up mode)</td>
</tr>
</tbody>
</table>

[3] Prelim calcs by K. Harkay

Slide courtesy Y. Ivanyushenkov
Preliminary calculations: electron cloud heat load vs. bunch spacing

Assumptions (*posinst*):
- 8 mm vacuum chamber, field-free
- 20 bunches, 5 mA/bunch
- Al: $\delta_{\text{max}} = 3.0$; TiN: $\delta_{\text{max}} = 1.1$
- Simple photon reflectivity model

Uncertainty for electron beam:
- APS positron modeling results agreed well with RFA data
- APS electron beam modeling did not agree well
- Data also from CesrTA suggest that photoemission model needs improvement.

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Multipacting resonance, e+ and e- beams at APS

Comparison of APS RFA data with *posinst* simulated electron cloud wall current as a function of bunch spacing (20 mA, 10 bunches).

- Multipacting resonance peak position, amplitude, and peak width well modeled, sensitive in detail to secondary electron params (drift region)
- Avg. wall-impact energy well predicted (100 eV)
- Weak dependence on photoelectron params

- Electron beam poorly modeled with same parameters (100 Ah additional conditioning, reducing $\delta_{\text{max}}$)
- Avg. impact energy overestimated by factor 10 (150 eV vs. 10 eV msrd)
- Photoelectron model overly simplified – could not improve comparison
Negative beams can have a weaker BIM effect: APS electron beam, 2 mA/bunch

Assume standard chamber, 11-bucket spacing, field-free
Reflected photons absorbed between bunches (+ photoelectron)
Amplification can still occur, but effect is weaker
Product of electron cloud impact energy and flux on wall results in a power load
Electron beam: weak cloud buildup, highest near EA

Electron beam:
- The signal near EA (RFA 1) is always higher than RFA 6. Suggests that photoelectrons contribute most here.
- Pressure rise and beam lifetime degradation was observed for certain 100-mA fill patterns, but quickly conditioned away.
• A lorentzian primary energy distribution has been added to POSINST
• To fit data at high beam energy (especially electron beam data), a high value for the “scale parameter” (HWHM) of the distribution is needed
• Next few slides show several examples of this
  – Left hand plots show RFA data at +50V, compared to simulation with and without secondaries
  – Right hand plots show data/simulation comparison from -20 to -240V, for central, intermediate, and outer collectors
  – Upper plots have HWHM 5eV
  – Lower plots have HWHM 150eV
  – All plots are of the recently installed Al drift chamber at 15W
    • All data was taken on the same day
    • Beam conditions: 5.3 GeV, 14ns spacing

Slide courtesy J. Calvey
Slide courtesy J. Calvey

Conax #26 Collector Comparison, +50V on Grid, Original Parameters

conductor current (mA)

collector number

Conax #26 Collector Comparison, +50V on Grid, width = 150 GeV

conductor current (mA)

collector number

Conax #26 Collector Comparison, width = 150 GeV

Collector current (mA)

Retarding Voltage (-V)
Effects for electron beams: summary

- Weaker multipacting effect in drifts compared with positron beams.
- Electron-stimulated gas desorption can cause pressure bump, lifetime effect
  - Observed in APS when studying multiplet fill patterns
  - Certain bunch patterns had half the beam lifetime, correlated with larger RFA signals. Effect no longer observed months later due to surface conditioning.
- Electron-beam data at APS and CesrTA suggest that photoelectron distribution should have a longer energy tail. Preliminary simulations show improved agreement:
  - Photoelectron energy modeled as narrow low-energy Gaussian distribution reasonably matched 2 GeV data, but broader energy width of 150 eV matched 5 GeV data better in POSINST (J. Calvey)
  - Studies with shielded buttons and photoelectron model in ECLOUD (J. Crittendon – see poster)
- RFA data in wigglers at CesrTA relevant, but dynamics will be different since chamber is room temperature.
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Clearing electrodes most effective EC mitigation in CesrTA wigglers

![Graph showing wiggler comparison, 1x45 e+, 2.1 GeV, 14ns](image)

- TiN coating most effective in drifts
- Grooves most effective in dipoles
- Biased electrodes most effective in wiggler RT chamber

TiN coating does not significantly reduce cloud.

- All comparisons for positron beam

Figure 8: Wiggler comparison, 1x45 e+, 2.1 GeV, 14ns


Shield SCU chamber

- SCU chamber tapers down in two steps from standard arc chamber (85 x 42) mm to SCU chamber (53 x 7.2) mm (full width x height)
- Usual ray-tracing has been done for shielding high-energy x-rays from outer chamber wall
- Lower-energy photons (> 4 eV) intercept SCU chamber top and bottom
- Preliminary thoughts on taper designs to
  - shield photons and minimize photoelectron generation in SCU field
  - minimize photon reflections *a la* LHC beam shield
- *Modeling of APS SCU chamber with synrad3d to be done*
  - Also study diffuse scattering, fluorescence
- Need data for photoelectron model (RFA, XPS, dedicated measurements)
Schematic photoemission spectra vs photon energy


Fig. 5.3 Energy ranges and specialized spectroscopies in photoemission. XPS, excited by soft X-rays, shows spectra of considerable complexity including core level spikes, Auger peaks, valence-band emission and inelastic electrons. UPS has an intrinsically higher resolution and cross section for the valence band. The bandstructure regime, $E_g = 10$ eV, shows sharp structure arising from bulk selection rules. Threshold emission is generally observed without energy analysis. Subthreshold spectroscopy requires additional means to emit photoexcited electrons over the work function barrier $\phi$, such as, e.g., a high electric field.
References

- LBNL Mirror reflectivity database
- LHC “crash program” (2000-2004)
  - Articles in ICFA Beam Dynamics Newsletter No. 33 (April 2004) by F. Zimmermann, p. 150; and J.M. Jimenez, p. 137.
Possible risk of an electron-cloud-induced heat load and vacuum effects for SCU (e.g. ANKA)

Electron cloud generation and buildup widely-studied for positron and proton rings; far less data for electron rings

Photoemission can be important for positron beams, but most attention has been paid to mitigating secondary electron emission

Secondary emission parameters cannot explain observations in electron rings; photoemission model incomplete

EC mitigation strategies focused on shielding SCU chamber from photons > 4 eV and minimizing photon reflections

Longer-term strategy may include clearing electrodes

Photon reflection study with synrad3d to be applied to APS SCU

Need data for photoelectron model (RFA, XPS, dedicated measurements)

See Laura’s talk