Alignment of Superconducting Undulators at the APS

Jaromir M. Penicka
for the APS SCU team
Outline

- Introduction
- SCU design overview
- SCU0 Assembly and fiducialization
- Cooling displacement compensation
- Alignment in the APS storage ring
- Final beam-based alignment and monitoring
- Summary
Advanced Photon Source (APS)
SCU0 team

**Core Team**

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- V. Syrovatin
- V. Tsukanov
- V. Lev

**FNAL Collaboration**
(Resin Impregnation)
- A. Makarov

**UW-Madison Collaboration**
(Cooling System)
- J. Pfotenhauer
- D. Potratz
- D. Schick

**Technical Support**
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- R. Farnsworth* (AES-CTL)
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- J. Dooling (ASD-AOP)
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- R. Flood (ASD-AOP)
- M. Jaski (ASD-MD)
- J. Lang (ASD-ESH/QA), J. Lang (XSD-ADD)
- F. Lenkszus (AES-CTL)
- D. Robinson (XSD-MM)
- V. Sajaev* (ASD-AOP)
- K. Schroeder (ASD-AOP)
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- H. Shang (ASD-AOP)
- R. Soliday (ASD-AOP)
- X. Sun (ASD-DIA)
- A. Xiao (ASD-AOP)
- A. Zholents (ASD-DD)

**Former management:** E. Moog† (ASD-MD)

**Associate Project Manager:** M. White (APS-U)
SCU cryostat

Cryostat vacuum vessel
He fill/vent turret
Cryocooler
Current leads
Beam chamber flange
Cryocooler
Vacuum pump
Cryocooler

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SCU0 cryostat structure

SC magnet
He fill/vent turret
LHe vessel
LHe piping
20 K radiation shield
60 K radiation shield
Beam chamber
Beam chamber thermal link to cryocooler
### SCU0 and SCU1 parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SCU0</th>
<th>SCU1</th>
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<tbody>
<tr>
<td>Electron beam energy</td>
<td>7.0 GeV</td>
<td>7.0 GeV</td>
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<tr>
<td>Photon energy at 1\textsuperscript{st} harmonic</td>
<td>20-25 keV</td>
<td>12-25 keV</td>
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<tr>
<td>Undulator period</td>
<td>16 mm</td>
<td>18 mm</td>
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<tr>
<td>Magnetic gap</td>
<td>9.5 mm</td>
<td>9.5 mm</td>
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<tr>
<td>Magnetic length</td>
<td>0.33 m</td>
<td>1.14 m</td>
</tr>
<tr>
<td>Cryostat length</td>
<td>2.06 m</td>
<td>2.06 m</td>
</tr>
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</table>
# Alignment Tolerances

<table>
<thead>
<tr>
<th>Alignment Tolerance</th>
<th>X [mm]</th>
<th>Y [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic structure</td>
<td>±0.150</td>
<td>±0.150</td>
</tr>
<tr>
<td>SCU0 vacuum chamber relative to the magnetic structure</td>
<td>N/A</td>
<td>±0.150</td>
</tr>
<tr>
<td>SCU0 vacuum chamber relative to the U33 ID chamber</td>
<td>±0.150</td>
<td>±0.150</td>
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</tbody>
</table>

The Challenge of Alignment?

- How to align an object suspended by Kevlar
- That changes temperature by 300 degrees K
- And is encapsulated like this?
Cold Mass
20 K Radiation Shield
60 K Radiation Shield
Vacuum Vessel
Cold Mass Assembly

Support frame – magnet structure – vacuum chamber

- Conventional optical tooling methods
- Tolerance ±75 microns in X,Y achievable
Cold Mass Fiducialization

- Optical Tooling
- Articulating CMM (FARO)
Kevlar band suspension system

- The alignment of the cold mass within the vacuum vessel assembly was accomplished by adjusting the Kevlar suspension bands.
- The coordinates of the vacuum vessel and cold mass fiducials were monitored with the laser tracker and N3 optical level.
Cooling Displacement Test
Cooling Displacement Test

- The seven pairs of spherical targets were placed in the beam chamber at predefined locations.
- The pairs of sphere targets were "spring-loaded" with stiff wire to engage the cylindrical profile of the chamber in the horizontal plane.
- By observing the top and bottom edges of the spheres by N3 optical level the vertical position of the beam chamber was measured during the cool-down and warm-up cycle.

Spherical target inside the prototype of the SCU0 vacuum chamber photographed through the alignment scope of the optical level.
Location of Spherical Targets

Positions 1, 3, 5, and 7 are at the beam chamber support locations.

Courtesy M. Kasa
Cool-down and Warm-up Cycle

Change in Vertical Position of the Beam Chamber from Room Temperature/No Vacuum

- Room Temperature and No Vacuum (Reference)
- Room Temperature and Ins. Vacuum Initial Measurement

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Courtesy M. Kasa
Cool-down and Warm-up Cycle

Change in Vertical Position of the Beam Chamber from Room Temperature/No Vacuum

- Room Temperature and No Vacuum (Reference)
- Room Temperature and Ins. Vacuum Initial Measurement
- Room Temperature and Ins. Vacuum After Bringing Cryostat to Atmosphere then Back to Vacuum

Courtesy M. Kasa
Cool-down and Warm-up Cycle

Change in Vertical Position of the Beam Chamber from Room Temperature/No Vacuum

- Room Temperature and No Vacuum (Reference)
- Room Temperature and Ins. Vacuum Initial Measurement
- Room Temperature and Ins. Vacuum After Bringing Cryostat to Atmosphere then Back to Vacuum
- Cold

Courtesy M. Kasa
Cool-down and Warm-up Cycle
Aluminum Links Compensation

- To eliminate displacement of the beam chamber/magnets assembly during the cooling process the Kevlar strings were modified with the aluminum links.
- The length of the aluminum links was calculated to compensate for the thermal elongation of Kevlar and thermal contraction of stainless steel part as well as mechanical elongation of the Kevlar caused by pressure difference.
SCU magnetic measurement

- Mitigation of the thermal shift verified during the next cool-down warm-up cycle.
- Beam chamber monitoring was incorporated into the magnetic measurement procedure.

Cold (20K) Al beam chamber

Warm (~300K) carbon fiber tube holding Hall probe or 4 mm wide integral coil or fiber optic alignment target

Vacuum

Air

X

Y

R2.0

72.0

53.0

7.2

.75

Mitigation of the thermal shift verified during the next cool-down warm-up cycle.

Beam chamber monitoring was incorporated into the magnetic measurement procedure.

Courtesy C. Doose
Alignment in the APS storage ring

- The SCU0 was installed in SR sector 6, downstream of a half-length ID chamber with 7.5 mm vertical aperture.
- An optical level and precision transit-square were utilized to position the SCU0 at its ideal location.
- A laser tracker oriented to the storage ring control network was used to provide a redundant quality assurance check.
- Beam-based alignment was foreseen as a necessary final step to confirm and fine tune the position of the SCU0 after cool-down.
Beam-based Chamber Alignment

- Chamber alignment critical to protect SCU0 from excessive beam-induced heat loads.
- Novel beam-based alignment using thermal sensors mounted on the SCU0 beam chamber was developed at APS. *
- Electron beam steering vertically and thermal sensor minima determine the vertical center of the SCU0 chamber with respect to the user beam orbit with 0.100 mm accuracy.

* K. Harkay et al.
Chamber alignment stability

SCU0 chamber vertical alignment Jan 2013 to Aug 2014

Sensor position (m)

y Center (mm)

2013Jan
2013Jul
2013Oct
2014Jan
2014Apr
2014Aug

Courtesy K. Harkay
Realignement of SCU0

Second realignment (Before: Aug 2014, After: Sep 2014)

Sensor position (m) vs. y Center (mm)

Before

After

Courtesy K. Harkay
User experiments with SCU0

**Diffraction pattern of 10-fold axis in new GdCd magnetic quasicrystal**


**Fluorescence mapping from nuclear fuel pellets**

Uranium and Thorium fluorescence maps of mock fuel pellets encased in Zirconium. G.J. Havrilla *et al.* to be published

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SCU1 improvements for alignment

- Added beam chamber viewports.
- Permanent fiducial cups in place of bushings.
- Improved Kevlar bands (no braiding, no knots).
Summary

- The first prototype superconducting undulator was successfully installed and aligned in the APS storage ring and has reliably delivered 80 – 100 keV photons to APS users for the last 19 months.
- A new spherical bead target technique was implemented for quantifying thermal shift of the SCU0 beam chamber.
- A unique suspension system combining Kevlar string with aluminum links was designed to eliminate any displacement of the chamber during the cooling of the SCU0.
- A novel beam-based measurement method using thermal sensors mounted on the SCU0 beam chamber was developed for fine alignment and stability monitoring.
- Significant knowledge was gained from the SCU0 installation, and many improvements are being implemented in the assembly and alignment of the next superconducting undulator, SCU1.
Thank you for your attention

感謝您的關注