Performance of SCU15:
The New Conduction-Cooled Superconducting Undulator for ANKA

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Outline

- Introduction to superconducting undulators
- SCU15 main parameters
- Design challenges
- System performance
- Summary
- Outlook
Superconducting undulators

Motivation

With respect to permanent magnet undulators SCUs can generate:

- Harder X-ray spectrum
- Higher brilliance X-ray beams

Why? Larger magnetic field strength for the same gap and period length

Same magnetic length = 2 m and vacuum gap = 5 mm

Brilliance ($10^{17}$ phs/s/m^2/0.1%mm^2)

$E = 3$ GeV
$l = 300$ mA
$s = 3$ nm rad

<table>
<thead>
<tr>
<th>$\lambda_u$ [mm]</th>
<th>$\lambda_u$ (SLS)</th>
<th>$\lambda_u$ (DLS)</th>
<th>$\lambda_u$ PrFeB*</th>
<th>$\lambda_u$ NbTi wire**</th>
<th>$\lambda_u$ NbTi APC***</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>17.7</td>
<td>15</td>
<td>15</td>
<td>15</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th># of periods</th>
<th>105</th>
<th>112</th>
<th>133</th>
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<tr>
<th>magn. gap [mm]</th>
<th>5</th>
<th>5.2</th>
<th>5.2</th>
<th>6</th>
<th>6</th>
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<table>
<thead>
<tr>
<th>B [T]</th>
<th>0.86</th>
<th>1.04</th>
<th>1.00</th>
<th>1.18</th>
<th>1.46</th>
</tr>
</thead>
</table>

| K               | 1.53            | 1.72            | 1.4             | 1.65            | 2.05            |

Simulations performed with SPECTRA*

*F. Bedeker et al., EPAC06
*C.W. Ostenfeld & M. Pedersen, IPAC10
*M.E. Couprie et al., FLS2012
*D. Saez de Jauregui et al., IPAC11
*T. Holubek et al., IFAC11


SCU15
Main parameters

- Formers with plate design
- Rectangular NbTi strand 0.35 mm X 0.53 mm
- No insulation between winding package and former
- Movable gap
- Cold corrector coils for minimization of field integrals
- Conduction-cooling design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
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<tr>
<td>Period length</td>
<td>15</td>
<td>mm</td>
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<tr>
<td>Full periods</td>
<td>100.5</td>
<td></td>
</tr>
<tr>
<td>Max field on axis 7 mm gap</td>
<td>0.73</td>
<td>T</td>
</tr>
<tr>
<td>Nominal current</td>
<td>150</td>
<td>A</td>
</tr>
<tr>
<td>Ramp to nominal current</td>
<td>450</td>
<td>s</td>
</tr>
<tr>
<td>Operating gap</td>
<td>7</td>
<td>mm</td>
</tr>
<tr>
<td>Injection gap</td>
<td>15</td>
<td>mm</td>
</tr>
<tr>
<td>Beam heat load</td>
<td>4</td>
<td>W</td>
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<tr>
<td>Design temperature</td>
<td>4.2</td>
<td>K</td>
</tr>
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</table>
SCU15
Unique challenges

- **Mechanical tolerances**
  - Flatness along 1.5 m < 50 µm
  - Period length deviation < 10 µm
  - Winding package deviation < 40 µm

- **Conduction cooling**
  - 4 GM cryocoolers capable of a total power of 5 W @ 4.2 K
  - Two separate cooling circuits for magnets and beam pipe
  - Thermal separation between coils and beam pipe

- **Flexible cold beam pipe**
  - Open and close from 7 mm to 15 mm at 10 K
  - Distance from coils to beam pipe < 0.12 mm along 1.5 m
  - Ultra high vacuum < 5 \cdot 10^{-9} \text{ mbar}
SCU15
The device

Mover system
RF bellow
Cryostat
Adjusting feet
Cryocoolers
Coils
Beam pipe
Thermal shield
Performance
Vertical tests at CERN

- Five thermal cycles
- Three successful repair processes
- Acceptable training memory after thermal cycling
- Stable operation at 150 A

SCU15
Assembly at BNG
Performance
FAT: cooldown and vacuum performance

- Pump down to $10^{-4}$ mbar within 24 hours
- System cooldown in 1 week
- Cooldown dominated by thermal capacity of aluminum components of the cold mass
- Base temperature of the coils with no current < 3.2 K
- Base temperature of the beam pipe ~10 K
Performance
FAT: operation with current

- Nominal current of 150 A reached without additional training
- Ramp to 150 A in 450 s with slow start to minimize dynamic losses
- Temperature increase during ramp < 0.25 K
- 12 hours system stability demonstrated with current in 10 ppm range
SCU15 in the ANKA ring
Operation in the ANKA ring

Reliable operation

- Reliable operations
- Good thermal decoupling between coils and liner (separated by < 200 um along 1.5 m)
Operation in the ANKA ring

Beam lifetime

- Beam lifetime not affected with SCU15 in the ring and in operation.
Operation in the ANKA ring

Flux measurement

- Flux through a pinhole of 50 um diameter at 14.9 m normalized to $I_{beam} = 100$ mA
- Main current in coils 50, 70, 90, 110, 130 and 150 A
- From 3$^{rd}$ harmonic position at max coil current 150 A, $B = 0.73$ T > $B = 0.62$ T* of CPMU using PrFeB with the same period length and beam stay clear

* M. E. Couprie et al., FLS 12, Newport News, VA (2012)
SCU15 is a full scale device reliably operating in the ANKA ring at KIT.

For the first time a SCU when operating in ring with beam reaches a higher magnetic field than a CPMU with the same geometry

Very encouraging results for the implementation of SCUs in low emittance light sources
SCU15 -> SCU20

Lessons learned

Lesson learned from the SCU15 project:

- Use standard low-carbon steel for the yoke
- Use a block design for the former
- Use round superconductor and insulate the former
- Minimize the cold mass weight
- Use the flexible pipe as magnet spacer
- reduce procurement risks and machining issues
- improve accuracy during assembly
- avoid electrical shorts between former and wire
- reduce the cooldown time
- improve the uniformity of the gap along the coils

These lessons learned have been implemented in the design of SCU20, a 20 mm period length, 1.5 m long device.
• The coils (in horizontal configuration) reached nominal current after a short training in the CASPER II facility at KIT

• According to the test results in CASPER II the specified field quality is reached

• An improved liner is being qualified
If you want the best insertion device for your light source

CONTACT US

We will deliver your SCU in 24 months

Thank you for your attention