RF PLANS FOR THE DIAMOND-II UPGRADE

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Diamond-II Upgrade

- Diamond-II improves quality of photon beams delivered to users
  - Increase spectral brightness and transverse coherence
  - Reduced source size, line-width
  - Optimise spectral range
- Achieved via reduction in natural emittance, increase in beam energy, new IDs

Diamond-II super-period

6 long straights, ~7.5 m long
18 standard straights, ~5.2 m long
24 mid straights, ~2.9 m long

Conceptual Design Report (May 2019)
https://www.diamond.ac.uk/Home/About/Vision/Diamond-II.html
Cavity type

<table>
<thead>
<tr>
<th></th>
<th>Superconducting</th>
<th>Normal conducting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall power losses</td>
<td>Minimal</td>
<td>Significant</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Complex</td>
<td>Simple</td>
</tr>
<tr>
<td>Field gradient</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Fault tolerance</td>
<td>Vulnerable</td>
<td>Robust</td>
</tr>
<tr>
<td>Footprint</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Complex</td>
<td>Simple</td>
</tr>
<tr>
<td>Higher order modes</td>
<td>Weak</td>
<td>Managed</td>
</tr>
<tr>
<td>Taper</td>
<td>Long</td>
<td>Short</td>
</tr>
</tbody>
</table>

- EU HOM-damped cavity
  - Latest iteration of cavity installed at BESSY, Alba and ESRF (scaled)
    - Flanged joint at base of HOM damper removed to address trapped mode
    - Pickup coated at ESRF
  - Two cavities have recently been installed in Diamond

<table>
<thead>
<tr>
<th>Cavity</th>
<th>Coupling</th>
<th>Q₀</th>
<th>Rᵣ</th>
</tr>
</thead>
<tbody>
<tr>
<td>N16</td>
<td>5.17</td>
<td>33,000</td>
<td>3.75 MΩ</td>
</tr>
<tr>
<td>N18</td>
<td>5.25</td>
<td>33,000</td>
<td>3.75 MΩ</td>
</tr>
</tbody>
</table>
• A new beamline will be installed in what is now the Diamond RF straight
• Cavities must move to mid-section straights
  – Cryostat cannot fit in shorter straight and provide clearance for front ends
  – HOM-dampers of NC cavity can fit around a modified front-end support
  – Space must be provided for amplifiers
  – Easier to fit multiple smaller amplifiers than smaller number of large amplifiers
Cavity operating parameters

- 460kW required for 300mA beam with all IDs

<table>
<thead>
<tr>
<th>Number of cavities</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal cavity coupling</td>
<td>3.8</td>
<td>4.3</td>
<td>4.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Individual cavity voltage</td>
<td>450 kV</td>
<td>386 kV</td>
<td>338 kV</td>
<td>300 kV</td>
</tr>
<tr>
<td>Generator power per cavity</td>
<td>104 kW</td>
<td>85 kW</td>
<td>73 kW</td>
<td>63 kW</td>
</tr>
<tr>
<td>Power dissipated per cavity</td>
<td>27 kW</td>
<td>20 kW</td>
<td>15 kW</td>
<td>12 kW</td>
</tr>
<tr>
<td>Power dissipated in all cavities</td>
<td>164 kW</td>
<td>140 kW</td>
<td>123 kW</td>
<td>109 kW</td>
</tr>
</tbody>
</table>

- Operation with 8 normal conducting cavities
  - Reduces voltage per cavity to conservative level
  - Minimises running costs
  - Gives acceptable total wall power losses
  - Allows redundant operation should one cavity fail
  - Enables cavities to fit in storage ring
Amplifier design

• Vacuum tubes
  – Proven IOTs or klystrons at 500 MHz
  – Tens of kV in HVPS
  – Limited redundancy
  – Obsolescence may become an issue

• Solid state amplifiers
  – LDMOS power transistors up to 1kW
  – Typically use 50V supplies
  – Easier to work with and less noise on beam
  – Extreme redundancy for fault tolerance

• Well over half of all Diamond faults are IOT related
  – There is no redundancy in Diamond IOT amplifiers
  – Amplifier must shut down to protect any IOT
  – Separate power supplies would be beneficial
  – Solid state amplifiers would provide necessary redundancy

• All light sources using solid state amplifiers report superior amplifier MTBF
• Several possible industrial suppliers exist
Digital LLRF offers flexibility and adaptability

Using Alba DLLRF in Diamond
- IQ or polar PI loops of the cavity field for amplitude and phase.
- Cavity tuning
- Fast interlock handling.
- Automatic start-up and conditioning
- Monitoring of RF signals
- Recording of main digital processing signals for post-mortem analysis

Features
- Based on the MicroTCA standard
- Perseus 601X advanced mezzanine card with Virtex6 FPGA
- 16 Channel 14-bit ADCs and 8 channel 16-bit DACs

Developing upgrade for Diamond-II
- MicroTCA 4 downconverter/vector modulator RTM
  - Manufactured by Struck under licence from DESY
  - 8 channel downconverter
  - 1 channel vector modulator
  - 350 MHz - 500 MHz (DWC8VM1LF)
  - 500 MHz - 3500 MHz (DWC8VM1)
Higher Harmonic Cavity

- Higher harmonic cavity is needed to
  - Minimise heating
  - Alleviate collective instabilities
  - Maximise beam lifetime
- Proven elsewhere
- Considering passive superconducting third harmonic cavity
  - CEA/SLS/Elettra design available from industry
  - Using cryogenic plant for Diamond
  - Detune is almost constant for all conditions allowing wide range of operating currents
  - Robinson destabilisation is small and can be damped by fundamental cavity detune

<table>
<thead>
<tr>
<th></th>
<th>Passive NC</th>
<th>Active NC</th>
<th>Passive SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pro</td>
<td>Simple</td>
<td>Can be optimised for any beam current</td>
<td>Operates to low current</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weaker Robinson instability term</td>
</tr>
<tr>
<td>Con</td>
<td>Optimal only at one beam current</td>
<td>RF amplifier required</td>
<td>Cryogenic system required</td>
</tr>
<tr>
<td></td>
<td>Strong Robinson instability term</td>
<td>Strong Robinson instability term</td>
<td>Narrow bandwidth</td>
</tr>
<tr>
<td></td>
<td>Sensitive to fill transients</td>
<td>Sensitive to fill transients</td>
<td></td>
</tr>
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**Transients with HHC**

- Gap in fill pattern induces a transient in HHC
  - Unequal bunch lengthening around ring
  - Optimal HHC operation for one bunch only
  - Effect can be reduced with multiple short gaps
  - What is the minimum gap required for ion clearing?

- Shorter bunch trains allow multibunch top-up
  - Multibunch charge is much higher than single bunch
  - Central bunch has longest lifetime
  - Effect is self-correcting as lifetime is lower for more populated bunches
  - Flat losses can be replaced by a multibunch top-up
Booster RF

• Booster cavity is required to operate near the lower end of its frequency range
  – Can extend range to lower frequencies by raising temperature of cavity
    • Average operating power is low and cavity self-heating is limited
    • Elaborate water distribution system is used to regulate operating temperature
  – Can extend frequency range by mounting tuner further off-axis

• Booster ring uses both currently installed PETRA 5-cell cavities
  – Can use existing Solid State Amplifiers to power cavities up to 1 MV each
  – Space for two EU HOM-damped cavities as back-up
Linac upgrade

- Top-up injection on Diamond disturbs users
  - Maximise bunch charge to minimise top-ups
    - Studying gun upgrade
  - Losses are greatest on injection into booster
    - 50% to 60% efficiency for SB injection
  - Better efficiency with higher linac energy
    - Also reduces dynamic range of booster
- Frequency change impacts most severely on linac
  - Bunch charge and beam energy fall off rapidly
  - Options:
    - new structures, temperature tuning, maintain original frequency

C. Christou, IPAC’21, MOPAB107
• RF plans for Diamond-II are advanced
• 499.511MHz, 2.7MV 460kW to beam in storage ring
• Eight EU HOM-damped cavities distributed in pairs around storage ring
• One solid state amplifier per cavity
• Digital LLRF operating on a microTCA platform
• 2.0MV in booster RF
• Using two PETRA 5-cell cavities and two single cell cavities for redundancy
• Linac upgrade from 100MeV to 150MeV to improve transmission into booster
• Linac gun upgrade will increase charge per shot
• Linac frequency can be changed with new structures or with temperature tuning
• Can manage operation at old frequency by controlling synchronisation of booster injection