Beam Orbit Stabilization at Diamond Light Source

Ian Martin

Talk Outline

• Facility overview

• Requirements for Beam Stability

• Source of orbit motion and passive measures taken

• Orbit control systems
  – Hardware (BPMs/corrector magnets)
  – Slow orbit correction scheme
  – Fast orbit correction scheme
Diamond Light Source

- Diamond is a 3rd generation synchrotron light source
- Under construction in Oxfordshire, UK
- Open to Users Jan 2007
- Consists of:
  - 100 MeV Linac
  - 100 MeV to 3 GeV Booster synchrotron
  - 3 GeV storage ring

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Grindelwald, Switzerland 6th – 10th Dec 2004

Diamond Light Source

Lattice DBA
Energy 3 GeV
Length 561.6 m
Symmetry 6 Fold
Structure 24 cell
Tune Point 27.23/12.36
Emittance 2.7nm.rad
Stripes 5.3m/8.3m
Energy Spread 9.6x10^-4

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Requirements for Beam Stability

- High brightness photon beam requires small electron beam size
- Specification is the beam motion is less than 10% of beam size at source points
- In standard straights:

\[ \beta_y = 1.53m, \ \kappa = 1\%, \ \varepsilon_y = 27 \ pm.rad \]

\[ \Rightarrow \sigma_y = 6.4\mu m \quad \sigma'_y = 4.2\mu rad \]

\[ \Rightarrow \Delta y < 0.6\mu m \quad \Delta y' < 0.4\mu rad \]

Sources of beam motion

<table>
<thead>
<tr>
<th>Source</th>
<th>Measures Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground motion</td>
<td>Piled building foundations (see later slide)</td>
</tr>
<tr>
<td>(settlement (&lt;125\mu m per 10m per year),</td>
<td></td>
</tr>
<tr>
<td>water table, vibrations (&lt;0.5\mu m pk to pk))</td>
<td></td>
</tr>
<tr>
<td>Thermal changes</td>
<td>Air temp controlled to 22+/-0.5 deg C</td>
</tr>
<tr>
<td>(BPMs can move ~a few \mu m)</td>
<td>Water temp controlled to 30+/-1 deg C</td>
</tr>
<tr>
<td>Magnet misalignment</td>
<td>Magnets mounted on girders (+/-70\mu m magnetic centre to girder alignment)</td>
</tr>
<tr>
<td>(magnet displacement ~100\mu m gives CO</td>
<td>Girders positioned by survey (+/-100\mu m)</td>
</tr>
<tr>
<td>errors ~a few mm)</td>
<td></td>
</tr>
<tr>
<td>Mechanical vibrations</td>
<td>Anti-vibration mounting where necessary</td>
</tr>
<tr>
<td>(from e.g. crane movement, water flow in</td>
<td></td>
</tr>
<tr>
<td>cooling pipes, power supplies (50Hz))</td>
<td></td>
</tr>
</tbody>
</table>

- Remaining motion corrected by closed orbit feedback schemes
Building Foundations

- **Final Solution for Building Foundations**
- **Void between slab and ground**
  - Eliminates local distortion due to ground swelling
- **Piled Foundations**
  - ~3m spacing, ~11m deep
  - Reduces settlement
- **Continuous slab**
  - 850mm thick in SR tunnel
  - 600mm thick in hall
  - Reduces elastic deformation under load
  - Improves dynamic performance

Investigations:

Integration of ground motion of bare site is 12nm in 1-100Hz frequency band (measured before construction started).

Plan to take new measurements in building during Dec 04/Jan 05.

Measure vibrations at various locations and for several different scenarios.

This will give good baseline measurements and characterize ground vibrations before accelerator components are installed.

Aids identification of new noise sources.
Storage Ring Girders

- 5 degrees of freedom for girder alignment using cam system
  - heave +/- 5mm
  - sway +/- 7.1mm
  - pitch +/- 4.1 or 3.0 mrad
  - yaw +/- 5.9 or 4.3 mrad
  - roll +/- 7.0 mrad

- Uses cone-V-flat system
- Range of motion limited by bellows

- Horizontal – Vertical Positioning System installed
  - range +/-2mm, resolution +/-1μm
- Possible upgrade to Hydrostatic Levelling System

Storage Ring Girders - Static Tests

- The systematic misalignments due to girder deflections under the weight of magnets have been modelled
- Resulting max/RMS quad displacements are 30μm/18μm
- Investigated how they affect closed orbit distortions, linear coupling and vertical dispersion
- Effects negligible, when compared to effects of additional random errors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Random Error</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet Alignment</td>
<td>+/-0.1mm</td>
<td>0.03mm (RMS)</td>
</tr>
<tr>
<td>Bend/Quad Roll</td>
<td>+/-0.1mm</td>
<td>0.2mrad (RMS)</td>
</tr>
<tr>
<td>Girder Displacement</td>
<td>+/-0.1mm</td>
<td>+/-0.1mm</td>
</tr>
<tr>
<td>Dipole Field</td>
<td>+/-0.1%</td>
<td>+/-0.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uncorrected</th>
<th>Just Random Errors</th>
<th>Random Plus Systematic Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS vertical CO</td>
<td>1.80mm</td>
<td>1.81 mm</td>
<td></td>
</tr>
<tr>
<td>RMS linear coupling</td>
<td>2.52%</td>
<td>2.52%</td>
<td></td>
</tr>
<tr>
<td>RMS vertical dispersion</td>
<td>4.56mm</td>
<td>4.56 mm</td>
<td></td>
</tr>
</tbody>
</table>
**Storage Ring Girders - Dynamic Tests**

- Fundamental modes of girders measured by LTC
  - 29 Hz (lateral rocking of support pillar B and flexure of the beam)
  - 38 Hz (lateral rocking of support pillar A and flexure of the beam)
  - 59 Hz (1st bending mode of the beam – lateral and vertical components)
  - 77 Hz (lateral bending mode)
  - 88 Hz (vertical bending mode)

- Transfer functions from 20-100Hz measured with dummy magnets
- Tests with real magnets still to be carried out

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**Orbit Control Systems**
Beam Position Monitors

- 168 electron BPMs (7 per cell)
- Locations decided from phase advance, beta functions and engineering considerations
- Resolution 0.3µm in normal mode, 3µm in turn-by-turn mode (current dependant)
- First turn capability

Primary Beam Position Monitors

- Primary BPM
- Primary BPM support stand (steel)
- Primary BPM reference pillar (carbon fibre – Coefficient of thermal expansion <0.2x10^-6 per degree)

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Correctors in Sextupoles

- 168 combined function correctors housed in sextupoles (7 per cell)
- 0.8 mrad deflection at 1 Hz
- 18 Bit resolution for power supplies
- 2mm thick stainless steel 316 LN vacuum vessel
- Available for Day 1
Fast Corrector Magnets

- Single function magnets
- 96 in each plane (4 per straight)
- 0.3 mrad deflection at 50 Hz
- 2mm thick stainless steel
- 316 LN vacuum vessel
- Not available on Day 1

Orbit Correction Scheme

- Diamond will use GLOBAL orbit correction
- SVD based algorithm to invert response matrix
- Flexibility over number of eigenvalues to use
Slow Orbit Correction

- Storage Ring has been modelled under various scenarios:
  - Expected magnet field errors
  - Expected magnet alignment tolerances
  - Effects of ground motion (Fourier, Gaussian, ATL)
  - Effects of mounting magnets on girders

<table>
<thead>
<tr>
<th>Error Type – With Girders</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girder Transverse Displacement</td>
<td>+/-100 µm</td>
</tr>
<tr>
<td>Girder Longitudinal Displacement</td>
<td>+/-200 µm</td>
</tr>
<tr>
<td>Element Transverse Displacement</td>
<td>σ = 30 µm</td>
</tr>
<tr>
<td>Element Longitudinal Displacement</td>
<td>+/-500 µm</td>
</tr>
<tr>
<td>Dipole Field Error</td>
<td>+/-0.1 %</td>
</tr>
<tr>
<td>Dipole / Quad Roll Error</td>
<td>σ = 0.2 mrad</td>
</tr>
<tr>
<td>BPM Transverse Displacement</td>
<td>σ = 50 µm</td>
</tr>
</tbody>
</table>

Closed Orbit in Straights

<table>
<thead>
<tr>
<th>Plane</th>
<th>Maximum</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>10.1 mm</td>
<td>2.3 mm</td>
</tr>
<tr>
<td>Vertical</td>
<td>2.9 mm</td>
<td>0.7 mm</td>
</tr>
</tbody>
</table>

Corrected

<table>
<thead>
<tr>
<th>Plane</th>
<th>Maximum</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.20 mm</td>
<td>0.05 mm</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.19 mm</td>
<td>0.06 mm</td>
</tr>
</tbody>
</table>

Corrector Strengths

<table>
<thead>
<tr>
<th>Plane</th>
<th>Max Correction</th>
<th>RMS Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.14 mrad</td>
<td>0.03 mrad</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.14 mrad</td>
<td>0.03 mrad</td>
</tr>
</tbody>
</table>

RMS CO distortions from ~2mm to ~50µm in straights

BPM positional accuracy limiting factor

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Dispersive Orbit Correction

- Dispersive orbit correction is to be done by adjusting the RF frequency
  - The mean fractional energy deviation $\frac{dP}{P}$ can be found from a 1D least-squares fit to the BPM data
  - This $\frac{dP}{P}$ corresponds to a frequency change of $df$
  - Once $df$ exceeds a certain magnitude, a change is made to RF frequency
- The dispersive orbit is subtracted from measured BPM data, and the dipole correctors are then only used to correct the closed orbit errors
- Helps to minimise the influence of closed orbit correction on the beam energy and dispersion

Dynamic Orbit Correction

- Expect correctors in sextupoles to be operated at higher frequency, up to limits imposed by vacuum chambers, signal processing and data transfer speeds
- 96 dedicated fast correctors will be added at the ends of the straights for fast orbit correction.
- These can be used in various ways depending upon the particular requirements:
  - Used as part of GLOBAL correction scheme in conjunction with correctors in sextupoles
  - Used locally on individual beam-lines at high frequency
  - Used in feed forward schemes
- Hardware will be in place, and there is flexibility in deciding how it is used
Dynamic Correction - Simulations

- Modelled with 0.2 µm RMS displacement on quadrupoles, sextupoles and BPMs
- Vertical beam size of 6.4 µm is tightest tolerance in straights
- Vertical divergence of 2.6 µrad tightest tolerance in dipoles
- Correction limited by BPM resolution

<table>
<thead>
<tr>
<th>Beam Size</th>
<th>σx (µm)</th>
<th>σx′ (µrad)</th>
<th>σy (µm)</th>
<th>σy′ (µrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDs</td>
<td>123</td>
<td>24.2</td>
<td>6.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Dipoles</td>
<td>36.8</td>
<td>87.2</td>
<td>24.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Residual Motion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xrms</td>
<td>0.23</td>
</tr>
<tr>
<td>Yrms</td>
<td>0.05</td>
</tr>
<tr>
<td>X′rms</td>
<td>0.23</td>
</tr>
<tr>
<td>Y′rms</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Top-Up Operation

- Diamond has been designed with future top-up operation in mind
- Top up provides constant heat load on accelerator components, and eliminates current-dependent effects for diagnostics
- Requirements:
  - Reliable injector
  - Closure of injection bump
  - High injection efficiency
- Collimators to be installed in BTS and SR injection straight to control emittance and energy spread

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kicker</td>
<td>Bend angle</td>
<td>0.45 deg</td>
</tr>
<tr>
<td>Kicker</td>
<td>Peak to peak</td>
<td>+/- 0.5%</td>
</tr>
<tr>
<td>Kicker</td>
<td>Mismatch</td>
<td>+/- 0.2%</td>
</tr>
<tr>
<td>Kicker</td>
<td>Roll error</td>
<td>0.2 mrad</td>
</tr>
<tr>
<td>Septum</td>
<td>Bend angle</td>
<td>8.5 deg</td>
</tr>
<tr>
<td>Septum</td>
<td>Peak to peak</td>
<td>+/- 500 ppm</td>
</tr>
<tr>
<td>Septum</td>
<td>Leakage Field</td>
<td>+/- 50 µTm</td>
</tr>
<tr>
<td>Septum</td>
<td>Roll error</td>
<td>0.2 mrad</td>
</tr>
<tr>
<td></td>
<td>Nominal bump size</td>
<td>13.7 mm</td>
</tr>
</tbody>
</table>
Acknowledgements

• Diamond/ASTeC Accelerator Physics Groups

  Riccardo Bartolini  Mahdia Belgroune  David Holder
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  Sue Smith         Jenny Varley    Naomi Wyles

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• Diamond Diagnostic Group
• .....