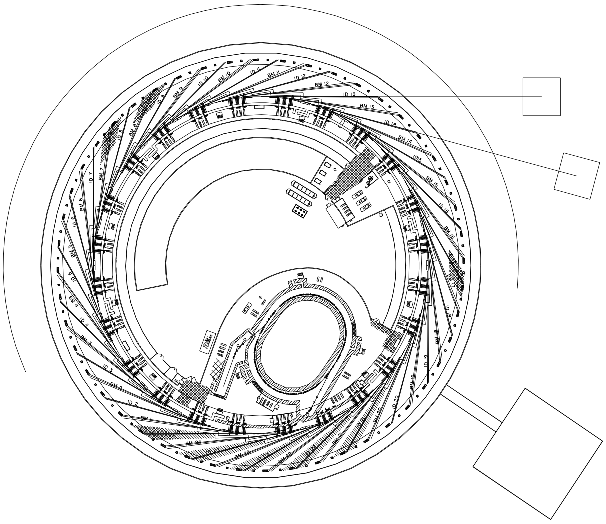
Beam Orbit Stabilization at Diamond Light Source

Ian Martin

Talk Outline

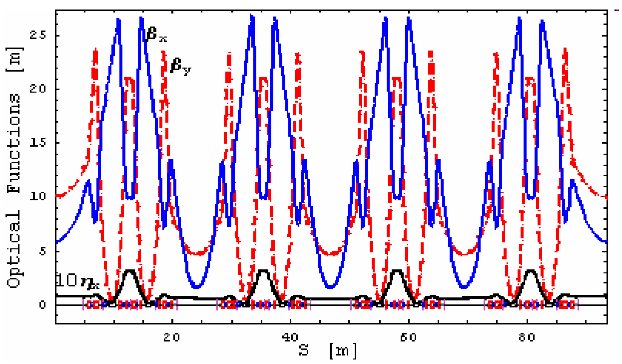
- Facility overview
- Requirements for Beam Stability
- Source of orbit motion and passive measures taken
- Orbit control systems
  - Hardware (BPMs/corrector magnets)
  - Slow orbit correction scheme
  - Fast orbit correction scheme

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

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
Straights	5.3m/8.3m
Energy Spread	9.6×10^{-4}

International Workshop on Beam Stabilization
Grindelwald, Switzerland 6th – 10th Dec 2004
diamond

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:

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

$$\Rightarrow \sigma_y = 6.4\mu m \quad \sigma_y' = 4.2\mu rad$$

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

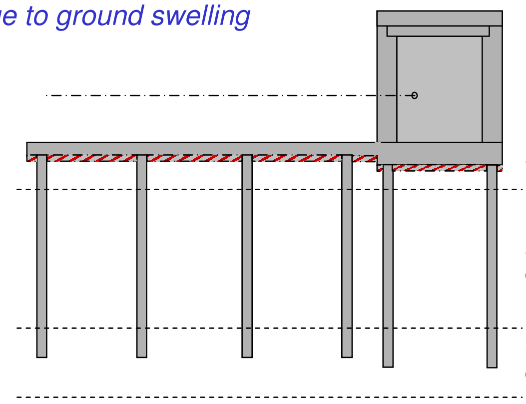
Sources of beam motion

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

- Remaining motion corrected by closed orbit feedback schemes

Building Foundations

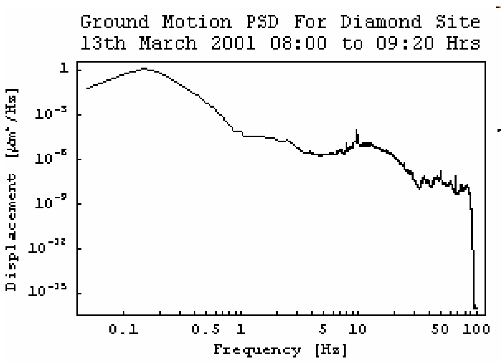
- *Final Solution for Building Foundations*
- *Void between slab and ground*
  - *Eliminates local distortion due to ground swelling*
- *Piled Foundations*
  - *~3m spacing, ~11m deep*
  - *Reduces settlement*
- *Continuous slab*
  - *850mm thick in SR tunnel*
  - *600mm thick in hall*
  - *Reduces elastic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



Courtesy Jacobs Gibb

Ground Vibration Measurements

- Integrated 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



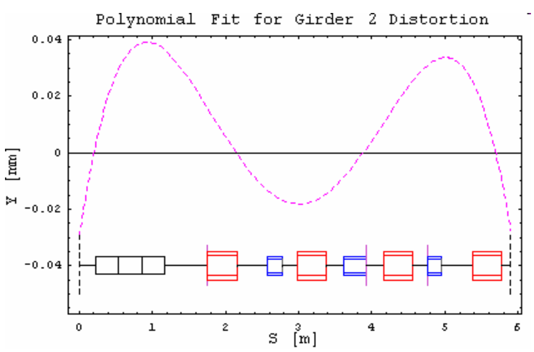
- This will give good baseline measurements and characterize ground vibrations before accelerator components are installed
- *Aids identification of new noise sources*

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*

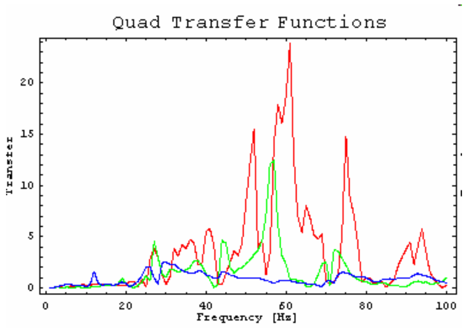
Random Error	Amplitude
Magnet Alignment	0.03mm (RMS)
Bend/Quad Roll	0.2mrad (RMS)
Girder Displacement	+/-0.1mm
Dipole Field	+/-0.1%

Uncorrected Parameter	Just Random Errors	Random Plus Systematic Errors
RMS vertical CO	1.80mm	1.81 mm
RMS linear coupling	2.52%	2.52%
RMS vertical dispersion	4.56mm	4.56 mm

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

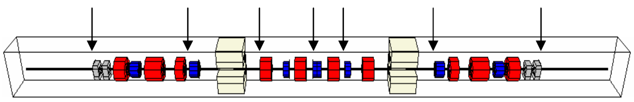


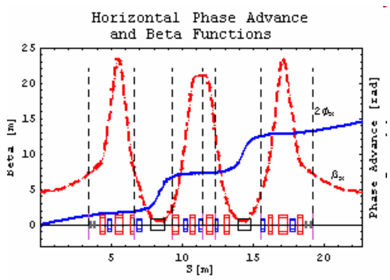
Orbit Control Systems

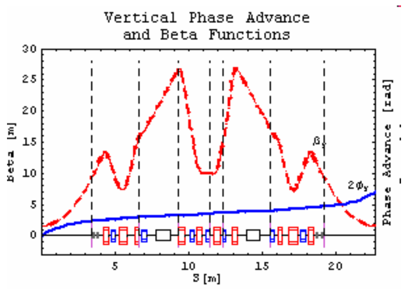
Beam Position Monitors

- 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

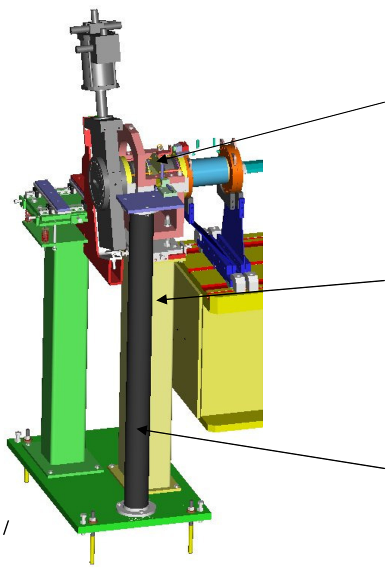
BPMs







Primary Beam Position Monitors



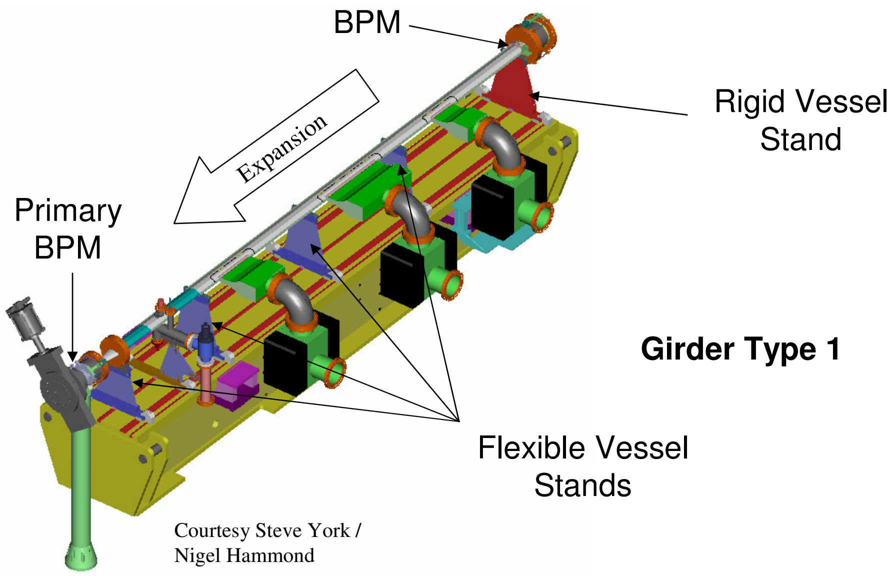
Primary BPM

Primary BPM support stand (steel)

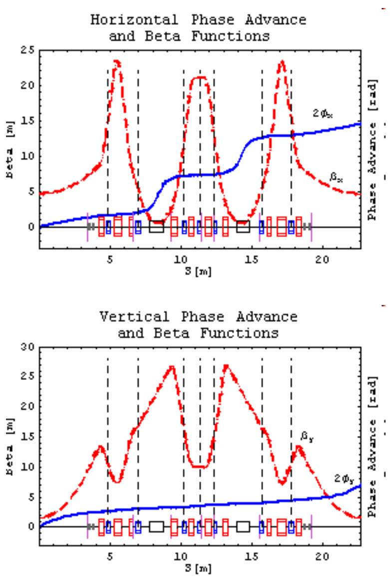
Primary BPM reference pillar (carbon fibre – Coefficient of thermal expansion $<0.2\times10^{-6}$ per degree)

Courtesy Steve York / Nigel Hammond

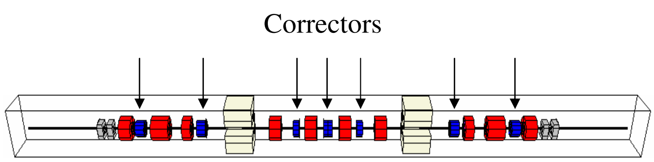
Standard Beam Position Monitors



Correctors in Sextupoles

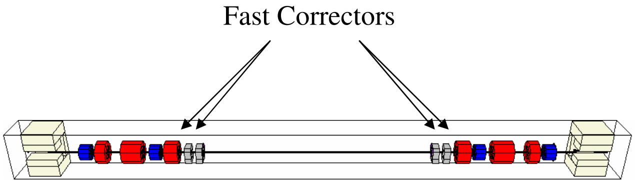


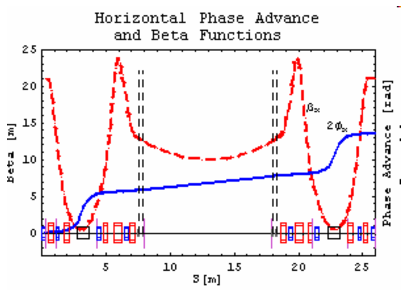
- 168 combined function correctors housed in sextupoles (7 per cell)
- 0.8 mrad deflection at 1 Hz
- 18 Bit resolution for power supplies
- 2mm thick stainless steel 316 LN vacuum vessel
- Available for Day 1

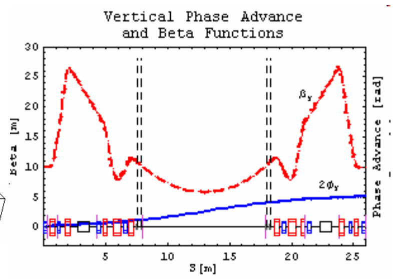


Fast Corrector Magnets

- 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

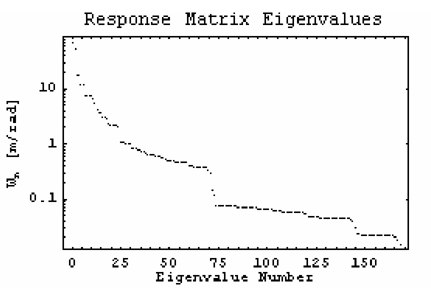


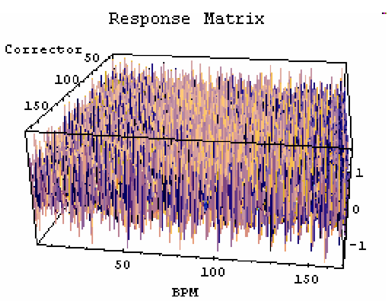


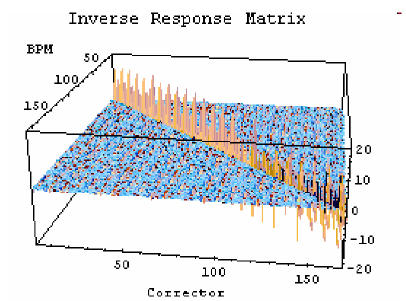


Orbit Correction Scheme

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







Slow Orbit Correction

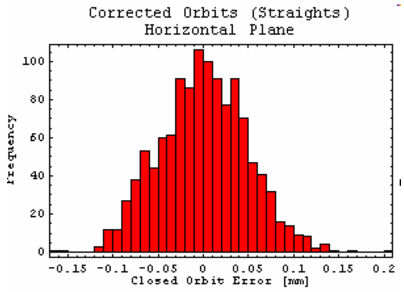
- Storage Ring has been modelled under various scenarios:
  - Expected magnet field errors
  - Expected magnet alignment tolerances
  - Effects of ground motion (Fourier, Gaussian, ATL)
  - Effects of mounting magnets on girders

Error Type – With Girders	Size
Girder Transverse Displacement	+/-100 μm
Girder Longitudinal Displacement	+/-200 μm
Element Transverse Displacement	σ = 30 μm
Element Longitudinal Displacement	+/-500 μm
Dipole Field Error	+/-0.1 %
Dipole / Quad Roll Error	σ = 0.2 mrad
BPM Transverse Displacement	σ = 50 μm

Slow Orbit Correction – With Girders

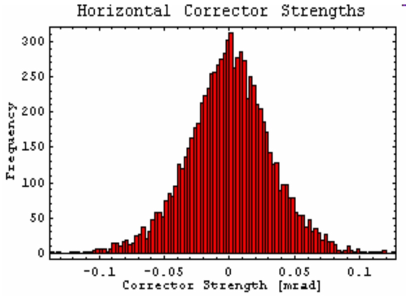
- Closed Orbit in Straights

Uncorrected	Maximum	RMS
Horizontal	10.1 mm	2.3 mm
Vertical	2.9 mm	0.7 mm
Corrected	**Maximum**	**RMS**
Horizontal	0.20 mm	0.05 mm
Vertical	0.19 mm	0.06 mm



- Corrector Strengths

Plane	Max Correction	RMS Correction
Horizontal	0.14 mrad	0.03 mrad
Vertical	0.14 mrad	0.03 mrad



- RMS CO distortions from ~2mm to ~50μm in straights
- BPM positional accuracy limiting factor

Dispersive Orbit Correction

- Dispersive orbit correction is to be done by adjusting the RF frequency
  - The mean fractional energy deviation dP/P can be found from a 1D least-squares fit to the BPM data
  - This 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

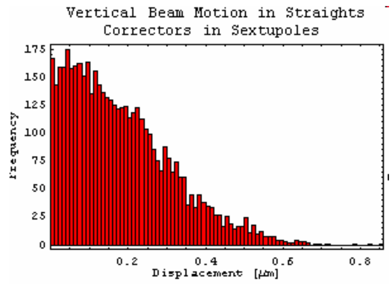
- Expect correctors in sextupoles to be operated at higher frequency, up to limits imposed by vacuum chambers, signal processing and data transfer speeds
- 96 dedicated fast correctors will be added at the ends of the straights for fast orbit correction.
- These can be used in various ways depending 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*

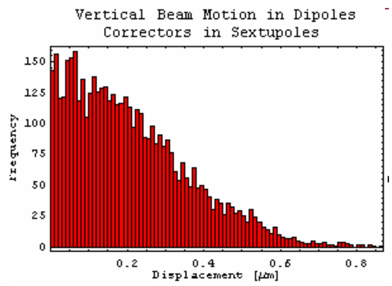
Dynamic Correction - Simulations

- 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

Beam Size	σ_X (μm)	σ_X' (μrad)	σ_Y (μm)	σ_Y' (μrad)
IDs	123	24.2	6.4	4.2
Dipoles	36.8	87.2	24.5	2.6

Residual Motion	X_{rms} (μm)	X'_{rms} (μrad)	Y_{rms} (μm)	Y'_{rms} (μrad)
IDs	0.23	0.05	0.23	0.05
Dipoles	0.29	0.26	0.26	0.23





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

Magnet	Parameter	Specification
Kicker	Bend angle	0.45 deg
Kicker	Peak to peak repeatability	+/-0.5%
Kicker	Mismatch	+/-0.2%
Kicker	Roll error	0.2mrad
Septum	Bend angle	8.5 deg
Septum	Peak to peak repeatability	+/-500ppm
Septum	Leakage Field	+/-50μTm
Septum	Roll error	0.2mrad
	Nominal bump size	13.7mm

- Collimators to be installed in BTS and SR injection straight to control emittance and energy spread

Acknowledgements

- Diamond/ASTeC Accelerator Physics Groups

Riccardo Bartolini	Mahdia Belgroune	David Holder
James Jones	Hywel Owen	Beni Singh
Sue Smith	Jenny Varley	Naomi Wyles

- Diamond Engineering Group
- Diamond Diagnostic Group
- …..

Thanks for listening!

International Workshop on Beam Stabilization
Grindelwald, Switzerland 6th – 10th Dec 2004
diamond