Survey and Alignment Update from the Diamond Light Source

David Wilson

Introduction to Diamond Light Source

- Diamond is a third generation, 3GeV synchrotron light source being constructed on the Chilton/Harwell science complex, South Oxfordshire in the UK
- 24-cell double bend achromatic lattice of 561.6m circumference
- Spectral output is optimised for high brightness up to:
  - 20keV from undulators
  - high flux up to 100keV from multipole wigglers.
- The accelerators are now all installed and 3 GeV commissioning of the storage ring is progressing well with stored beam at 10 mA
- 7 Phase 1 Beamlines planned for day 1 operation in Jan 2007
- Subsequent beamlines will be added at a rate of 4-5 per year

Progress Overview - Construction

- Construction commenced in December 2003 with the pouring of the first floor slab
- Storage Ring walls complete end of May 2004 except for a small area providing access to the central courtyard
- Access for Linac and Booster Installation September 2004
- Phased hand over of the Storage Ring commenced in October 2004 and completed in March 2005
- The first Storage Ring Girder installed in April 2005

Progress Overview - Linac

- Installation complete beginning August 2005
- First beam end of August
- 100 MeV injection energy achieved on 7th September
- All design parameters met by the end of October in both single and multi bunch modes of operation

Progress Overview - Booster

- Commissioning started in December 2005 with dc operation at 100 MeV
- First turn 21st December with no correctors which soon attained 1000 turns following minor adjustments
- First acceleration to 700 MeV achieved 10th March
- First acceleration to 3 GeV achieved 7th June once temp. cooling water became available.

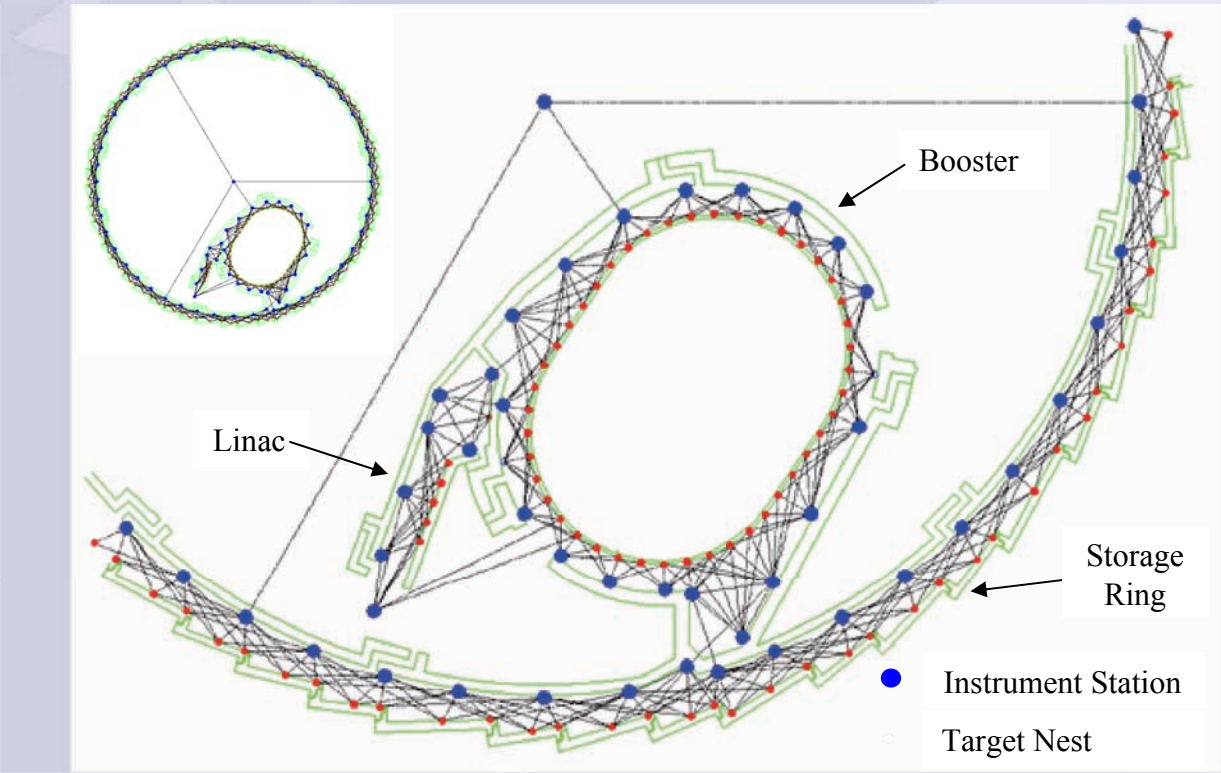
Progress Overview - Storage Ring

- Last girder installed March 2006
- Commissioning at 700 MeV commenced on 3rd May
- The following night saw the first turn followed by 4 and then 600 turns on successive evenings
- By 20th May Beam survival time was up to 100,000 turns (200 ms between injections from the Booster)
- 3 GeV commissioning commenced 4th September, 6 turns attained with RF off and nominal settings for the magnets
- 5 Days later, the beam was stored at 10 mA, commissioning continues!

diamond

Survey Networks

- The Diamond Accelerators are installed in 3 independent vaults housing the linac, booster and storage ring
- Each vault contains a survey network consisting of wall mounted survey monuments and wall and floor mounted target nests

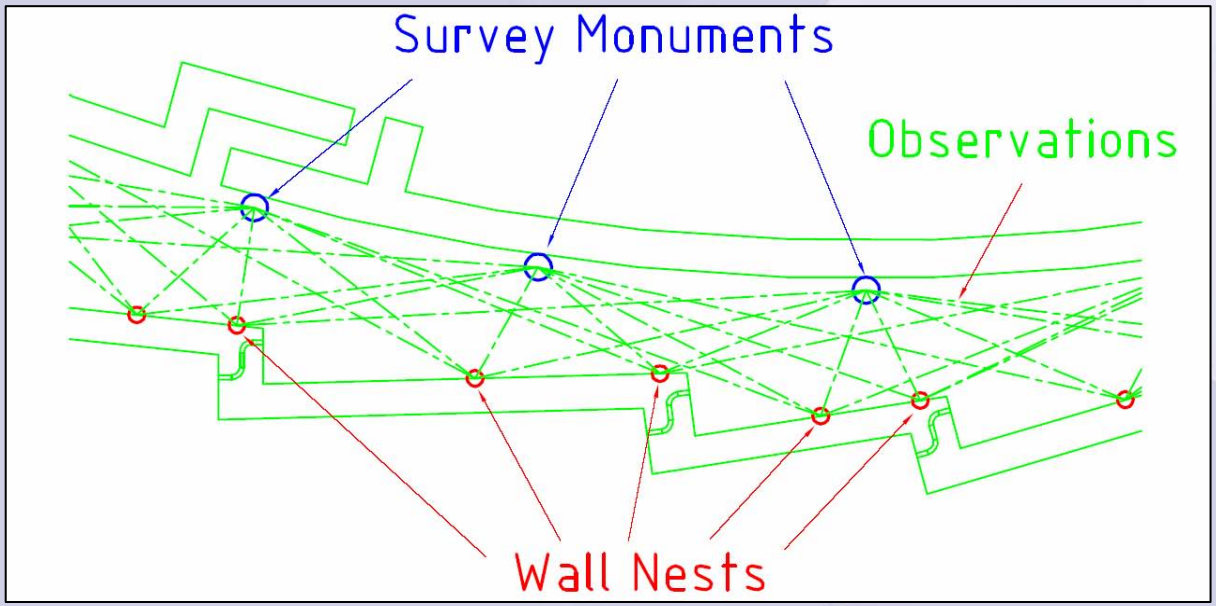


Planimetric network
TDA-5005

Altimetric network
Dini 12

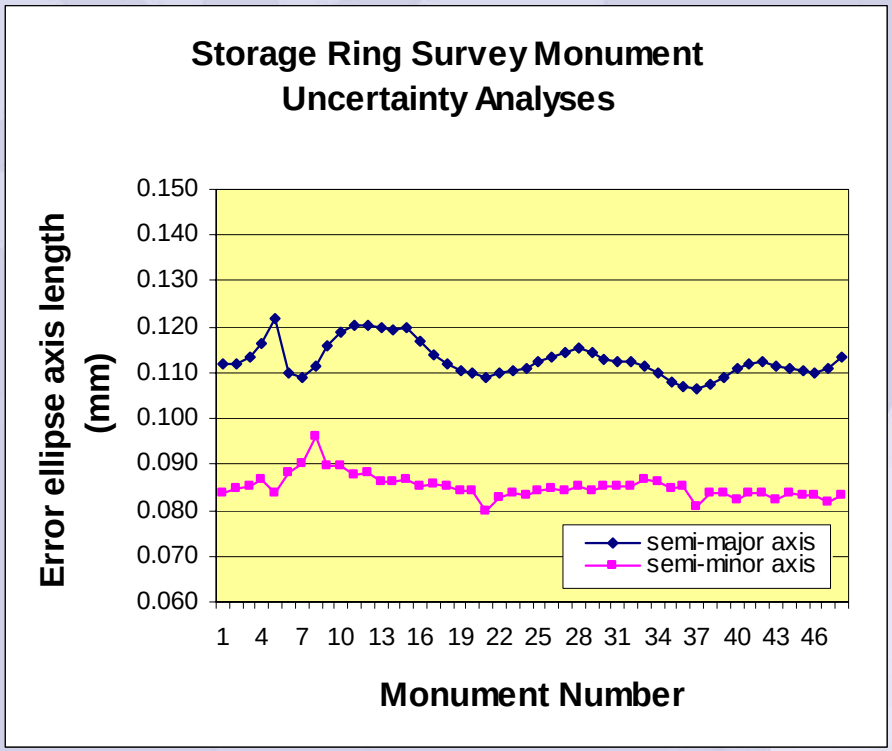
Storage Ring Tunnel Survey

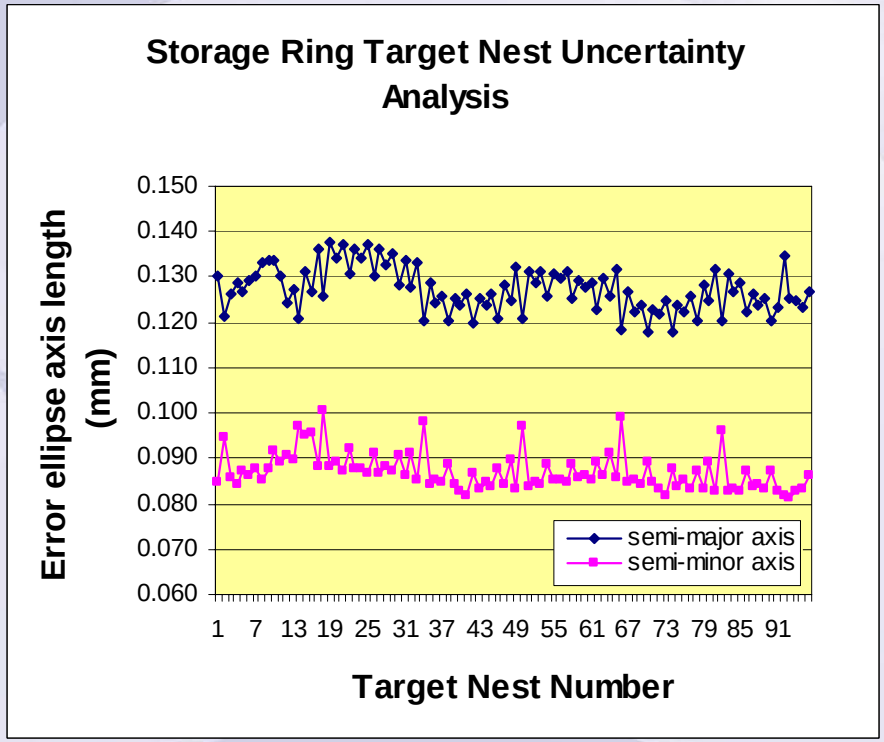
- Installation completed at the end of October 2004
- 48 Survey Monuments
- 96 wall nest
- A total of 384 observation for complete survey



diamond

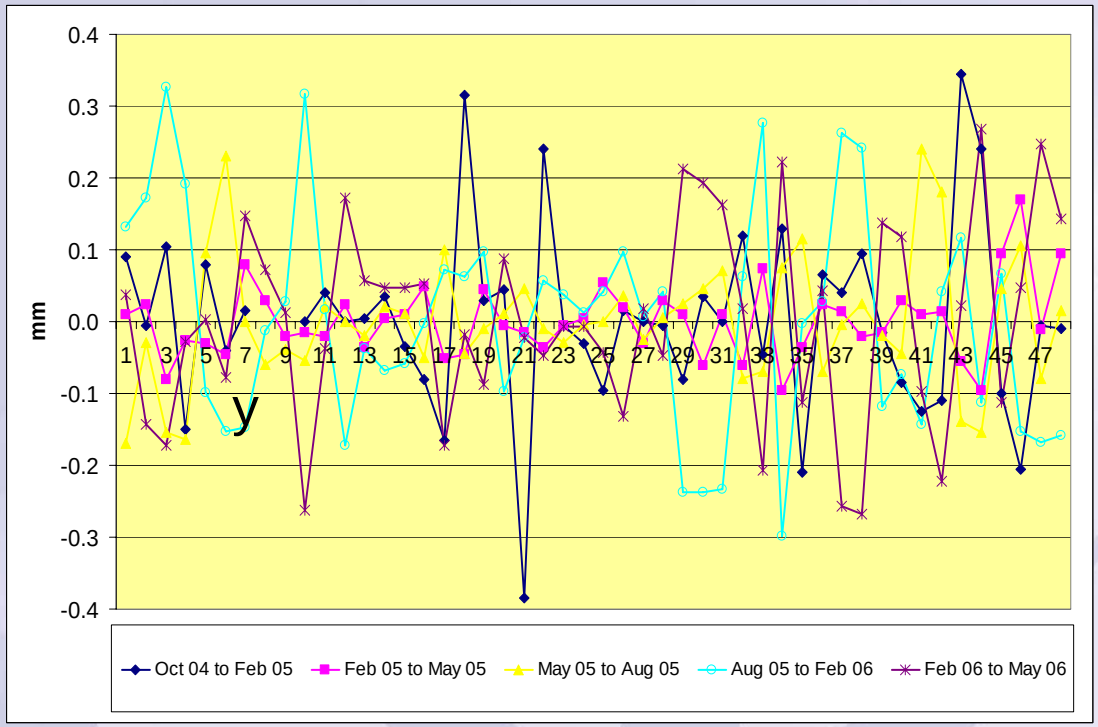
Storage Ring Network Uncertainty Analyses





Storage Ring Altimetric monitoring

- A 2-way levelling run of the 48 SR floor targets was first carried out in October 2004 and periodically repeated
- Graph plots the relative rise/fall between adjacent floor targets around the ring
- Global settlement of 2.5mm was seen during civil construction



- Reduced to 0.227mm over this 19 month period, benchmarked against the central site survey monument sat on a 12m deep pile

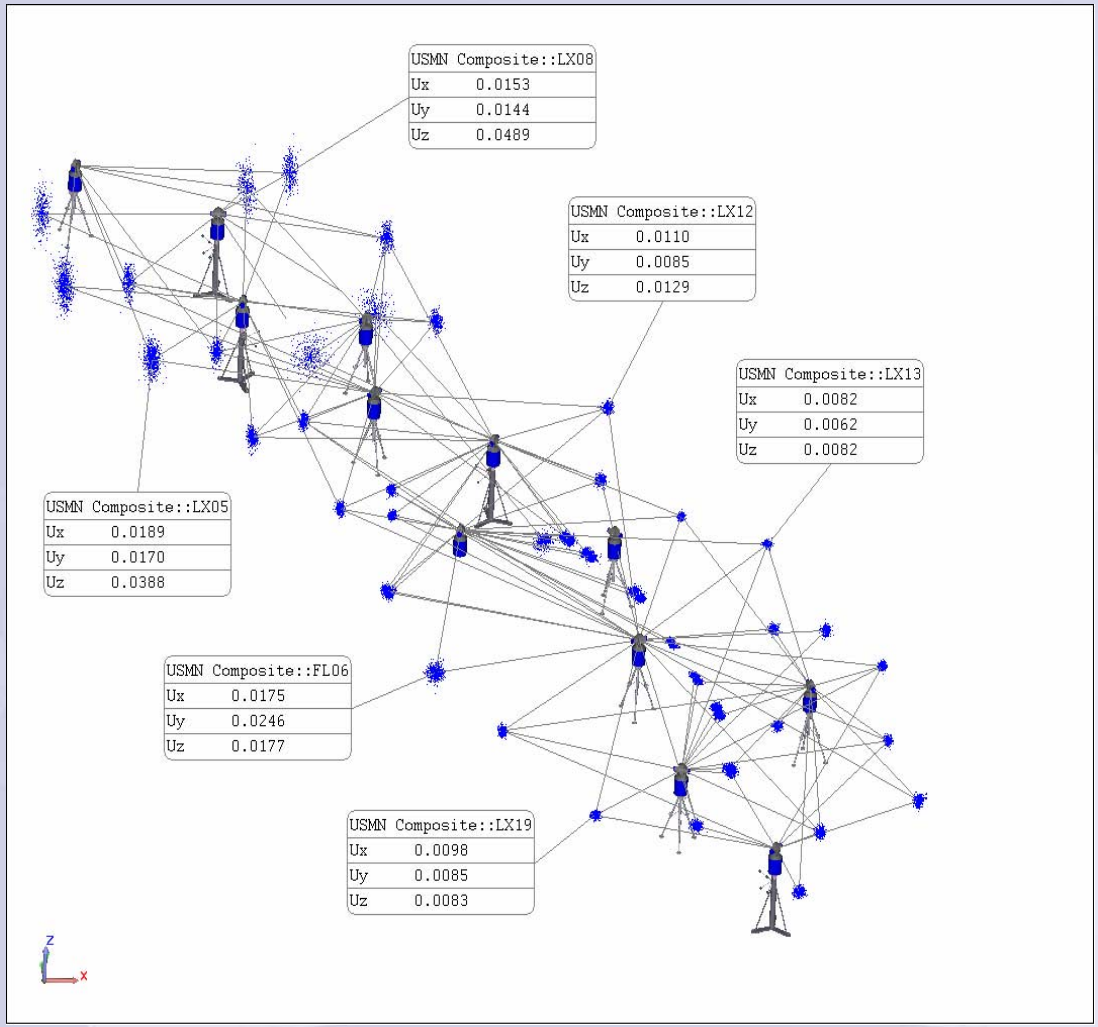
diamond

Linac Alignment

- The first accelerator components to be installed were the Linac and LTB 1 transfer line
- A Faro laser tracker running Spatial Analyzer (SA) software was selected for the alignment task:
  - Real-time measurement against nominal data provides direct feedback during the alignment process, optimising efficiency
  - Construction of alignment frames from mechanical features
  - The vault area would become very congested therefore a more dense network was required
  - Network adjustment and best fit functionality within SA allowed a 3D network to be aligned to our de-coupled planimetric and altimetric network

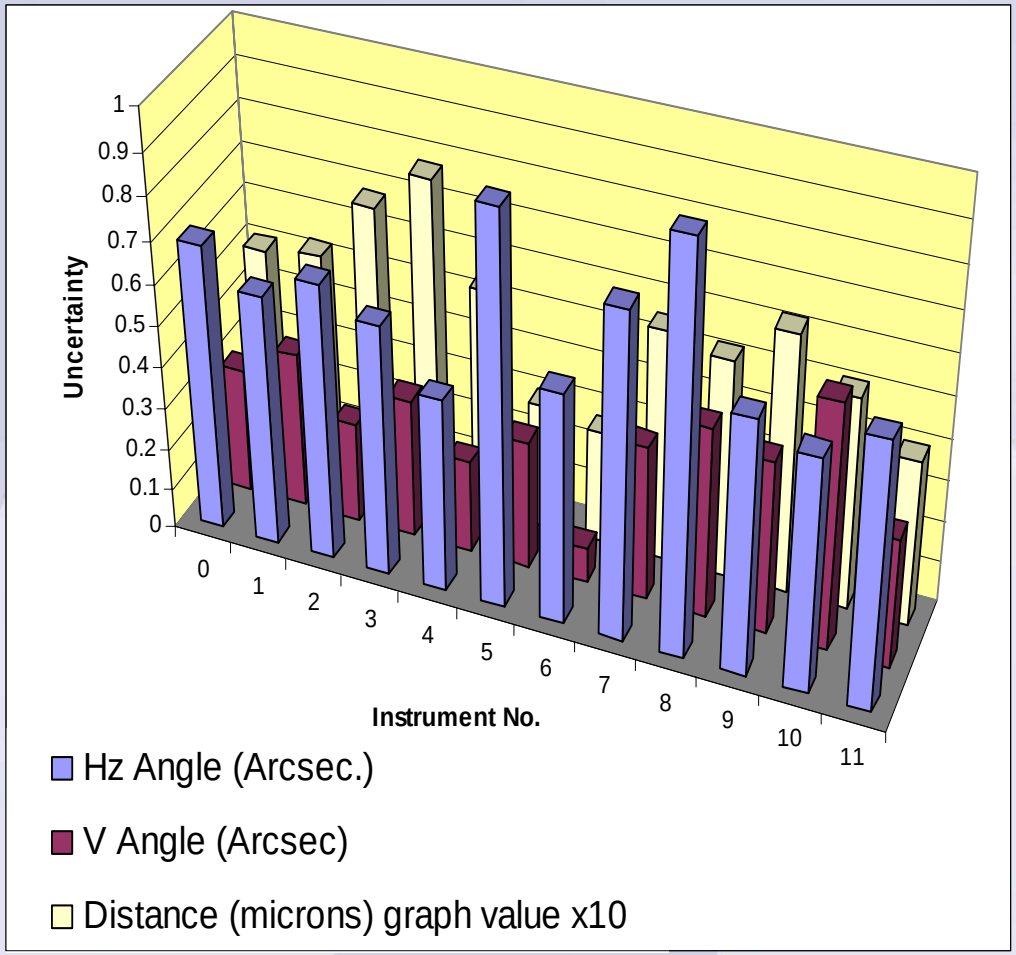
Linac Network Measurement and Adjustment

- 12 Instrument Station
- 52 points within the job
- 155 total measurements
- USMN used to best fit and then solve the network
- Statistical analysis tools flag up outliers from the residual fit data which can be isolated and the network re-calculated
- Uncertainties computed in 4.5 minutes on a Pentium 4, 3 GHz PC with 2 GB RAM



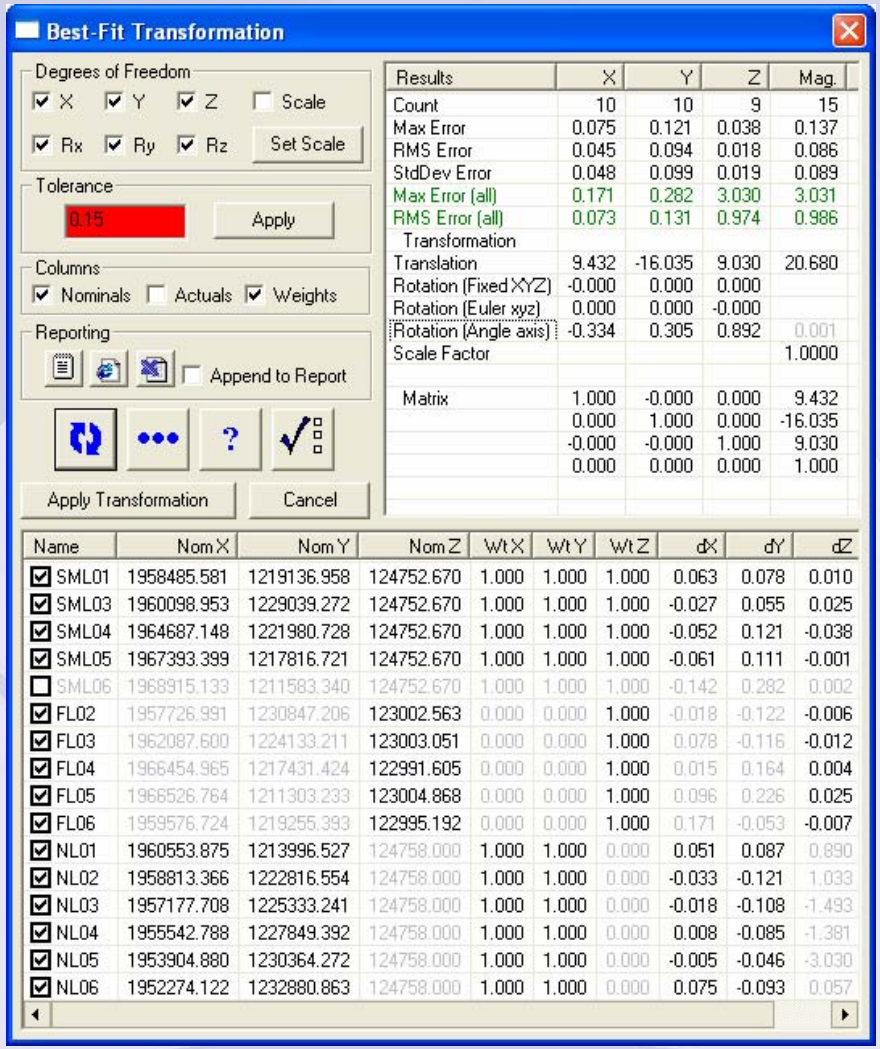
Linac Network – Instrument Uncertainty

- Default uncertainty setting for laser trackers within SA are:
  - 1.3 Arc seconds Hz angle
  - 1.3 Arc seconds V angle
  - 0.015 mm distance
- For this network the averages uncertainties were:
  - 0.6 Arc seconds Hz angle
  - 0.4 Arc seconds V angle
  - 0.006 mm distance



Linac Network – Best Fit to Global Network

- The network as it stood was coherent to itself but had no relationship to the site
- The global survey with total stations and levels provided de-coupled data for planimetric position and altimetric height
- A weighted best-fit transformation was applied to utilise the data in the available format



Component assembly in the Linac vault

- With the 3D network in place the laser tracker could be booked into the co-ordinate system anywhere in the vault
- The LTB components were fiducialised by the supplier therefore they could be aligned directly upon receipt
- The Linac components were fiducialised in the vault using external features such as flanges, planes etc

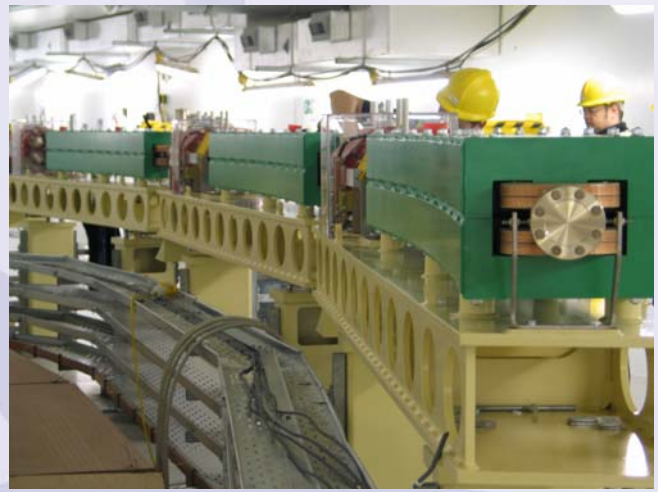
Booster Alignment

- The 44 booster girders were supplied as a turnkey contract pre-aligned by the supplier
- The installation sequence was to align every other girder to the network then infill the remainder
- A Faro laser tracker was selected for the task. Utilising its internal gyro as a gravity reference it was booked into the x,y values from the total station survey and the z values of the level survey

- The first 22 girders went in as planned however, the first infill girder identified a problem which was common for the whole supply.
- With the girders aligned to the network via their fiducials, a misalignment of the vacuum flanges was found. All vacuum vessels had to be inspected and the majority realigned before the installation could proceed

Booster Alignment

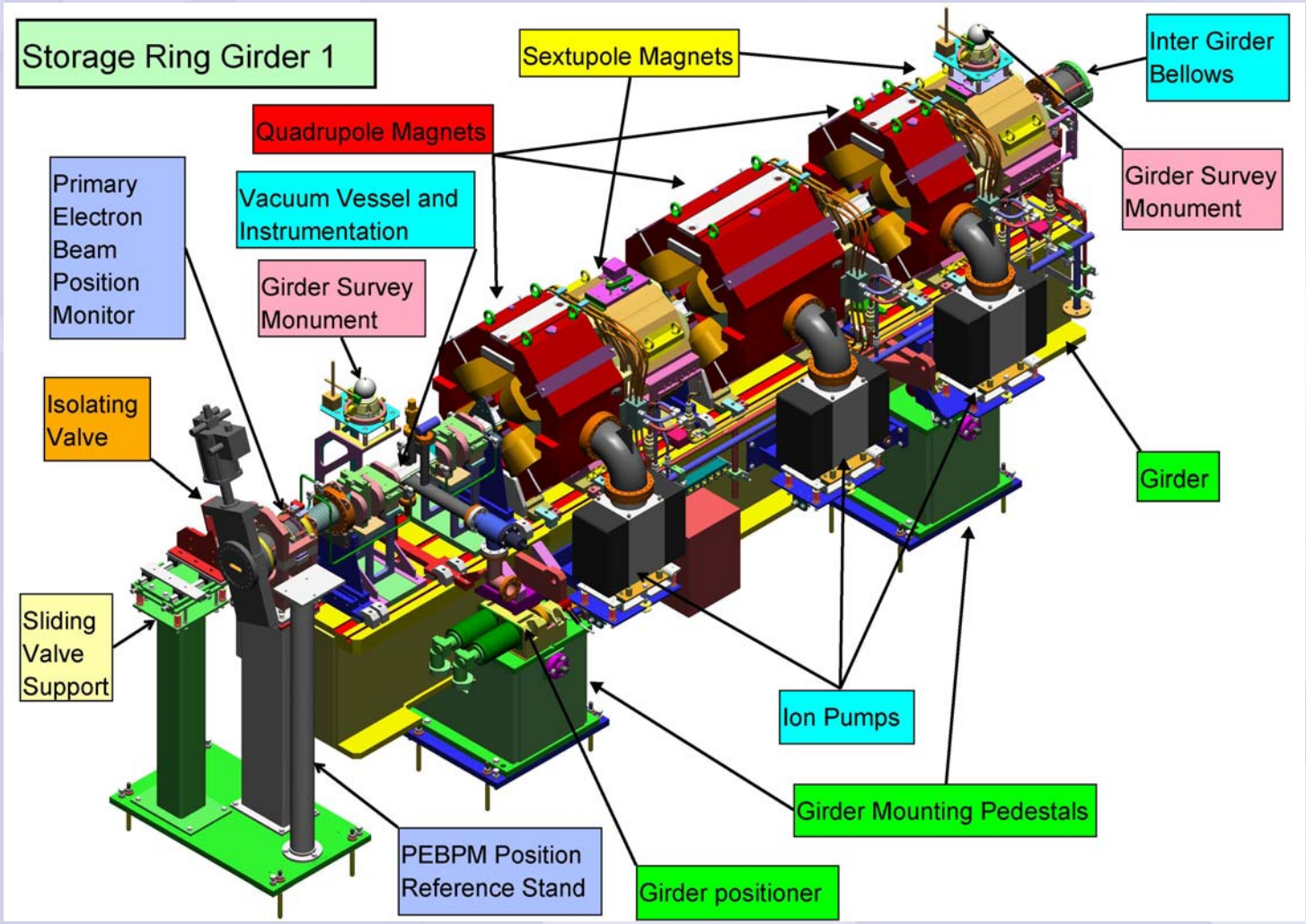
- Each girder assembly was inspected with the laser tracker to determine the adjustments required
- When the tracker moved on to the next girder a technician mounted dial gauges on the flanges at each end of the vacuum vessels and adjusted it into the requisite position
- Following a final inspection with the tracker, the girder was aligned and vacuum connections made.
- On completion of the installation a global survey of the complete booster was carried out and final adjustments made. No further adjustments to date



Storage Ring

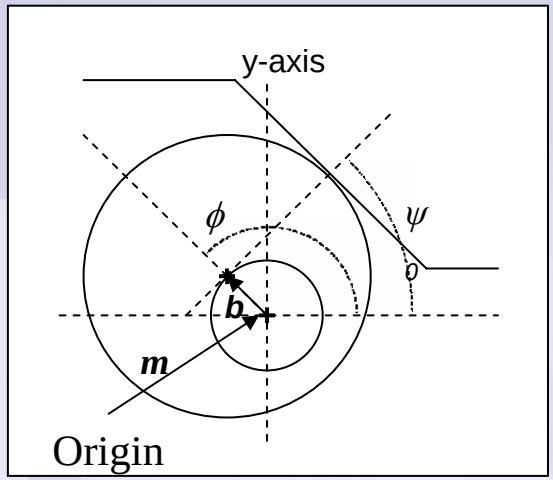
- Each of the 24 cells contain 3 girders which provide local alignment features for the magnets and vacuum chambers
- The girders come in 2 lengths ~ 5.9m and 4.3m, the longer girders accommodating the dipole magnets
- Keys and shims align each magnet onto its magnetic centre with reference to the girder
- Prior to installation each girder was fitted with a survey monument at each end, aligned to the alignment features of the girder at a pre-defined height above beam centre
- The Monuments have a dual function:
  - Provide the installation reference for the girder assembly
  - Provide an instrument interface for instrument stationing co-linear with the beamline axis.

Storage Ring Girder Assembly



Girder Alignment

- Each girder is fitted with a remote alignment system allowing automated motion in 5 degrees of freedom:
  - Sway, u (translation along *x* axis)
  - Heave, v (translation along the *y* axis)
  - Pitch, χ (rotation around *x* axis)
  - Yaw, η (rotation around *y* axis)
  - Roll, σ (rotation around *z* axis)



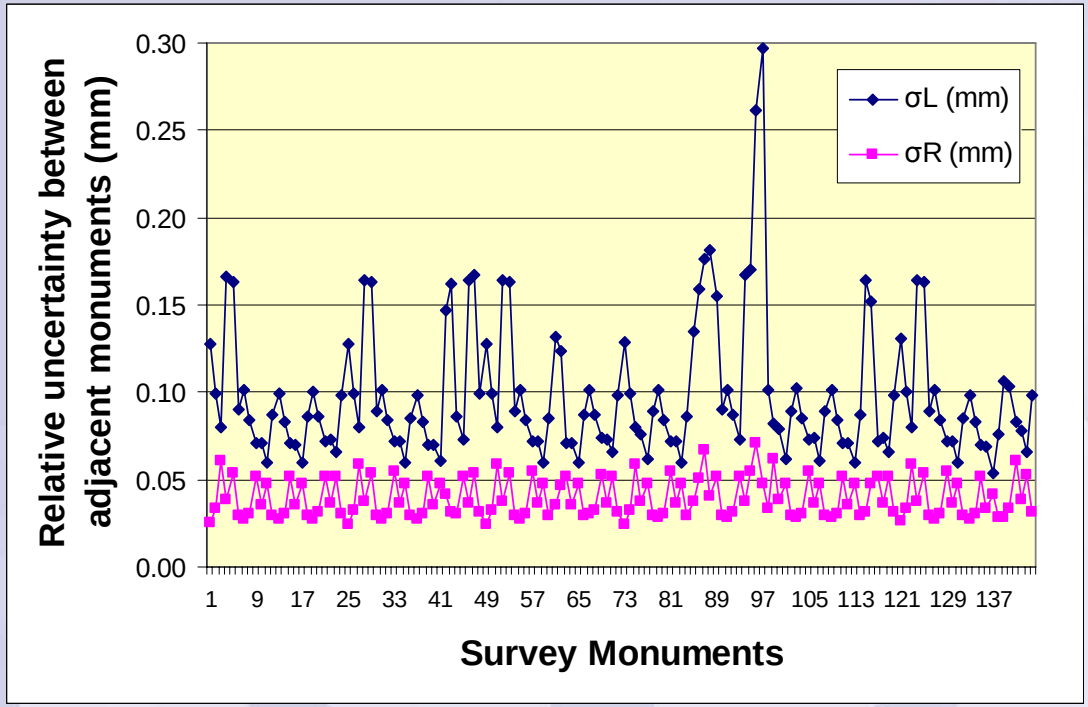
- Camshaft rotation Formula:

$$\phi = \psi_0 + \sigma \pm \cos^{-1}\left(\cos\psi_0 \frac{u - \sigma m_y + \eta m_z}{b} + \sin\psi_0 \frac{v + \sigma m_x - \chi m_z}{b}\right)$$

diamond

Initial Storage Ring Girder Survey (April 2006)

- Each girders survey monuments measured from 5 instrument stations
- 48 instrument stations
- TDA-5005 Total Station used for measurements, combining 3 face left & 3 face right shots
- Automated measurement process utilising instrument axis drives and ATR 30 minutes per station



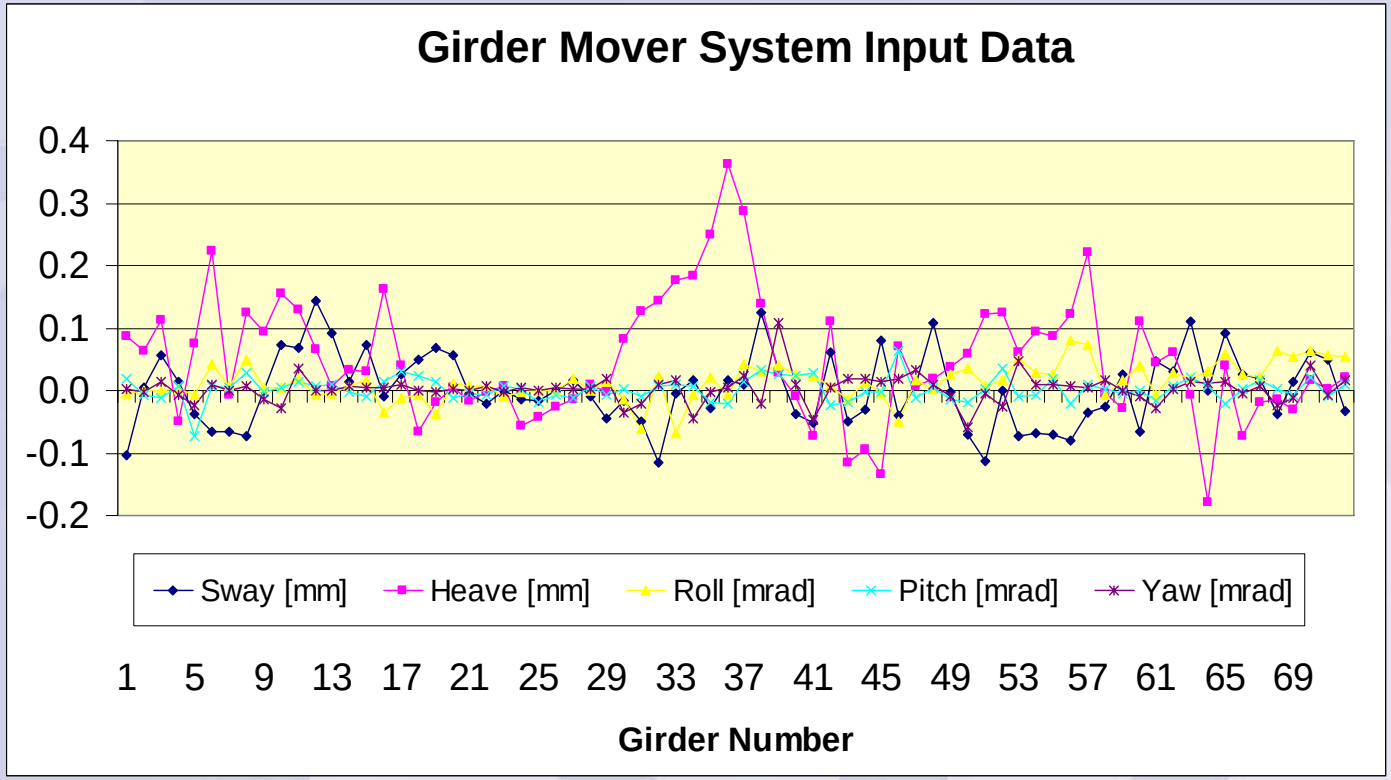
Survey carried out under less than ideal conditions with a number of sight lines blocked

Initial Storage Ring Girder Survey (April 2006)

- The level survey utilised the same instrument mount as for the total station
- A 2-way levelling run was carried out from each station
- Each rise/fall was valued from 2 independent stations and the collimation error calculated and corrected
- The closure error of the network was then distributed equally along the run (this survey closed to within 0.1 mm)
- The roll angle of each girder was measured using a nivel level 20 inclination sensor mounted on an interface plate
- This was measured twice with the instrument rotated through 180 degrees to eliminate any parallelism errors in the plate
- Combining the data sets provided sufficient information to define each girders 3-D spatial position and orientation and thus the input data for the mover system

August 2006 Storage Ring Survey

- Radial uncertainty maintained at 0.07 mm
- Longitudinal uncertainty within 0.16 mm in all locations



- Floor movement during the 4 months between surveys is evident and is typical of the relative movement seen during machine installation

Beamline Alignment

- Initial beamline activities included setting out hutch geometry and build reference lines from the exp. hall network
- Once the SR construction network was in place the beamline datum was established in each of the phase 1 hutches using alignment frames
- Now that the SR is installed and aligned it will become the primary datum for the beamlines
- Each beamlines alignment frame will now be qualified against the SR and if necessary adjusted accordingly prior to receiving beam.

Beamline Alignment

- In the majority of cases, beamline components were supplied with survey monuments at each end at a predefined height above the nominal beam centre
- This approach provided maximum flexibility for instrument selection:
  - Theodolites and levels could be combined for classical alignment techniques
  - Laser trackers could be used within a 3D network or in a level system (gyro-corrected)

Beamline Alignment

- Access permitting, the laser tracker was the preferred instrument for the majority of beamline alignment tasks
  - It does not have to be set up on beam axis to optimise accuracy as per a theodolite and its dynamic measurement properties provide real time measurement during alignment
  - The need for multiple operatives is removed resulting in a very efficient process.
  - Where survey monuments have not been provided, the laser tracker SA software can manipulate measured data to define alternative features such as flanges, planes holes etc to facilitate an alignment
  - Co-ordinate frames can be quickly generated and transformed to meet the requirements of the task and all of this can be carried out at the workplace
  - Software records all measured data maintaining full traceability

Conclusion

- The survey networks have achieved the design parameters for uncertainty and functionality
- Combining force-centred instrument mounts and floor/wall mounted target nests, provided a high degree of flexibility.
- SR surveys with TDA 5005 total stations proved successful both in terms of the results obtained and the time efficiency via automation.
- Faro laser trackers running SA software have provided an adaptable, portable 3D measurement system that has been regularly applied to a variety of tasks, both planned and unforeseen
- A desire for the future is to integrate digital level data within SA to consolidate the measurement process. This would allow a 3D network adjustment from a combination of total station angles and distances combined with elevations derived from digital level data, Diamond is currently working with SA's software developer New River Kinematics (NRK) in pursuance of this goal.

Acknowledgements

- Thank you to everyone in the accelerator alignment community who have assisted in the development of techniques used at Diamond
- Specific thanks go out to Tom Hosking for writing an instrument interface during his work experience placement at Diamond; this piece of work significantly improved the efficiency of the storage ring survey and is very much appreciated.