SURVEY AND ALIGNMENT FOR THE DIAMOND LIGHT SOURCE

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1. ABSTRACT

This paper covers the survey and alignment techniques selected for the installation and alignment of the Diamond accelerators, together with a current status report.

2. INTRODUCTION

Diamond is a third generation, 3GeV synchrotron light source being constructed on the Chilton/Harwell science campus, South Oxfordshire, UK, to support the life, environmental and physical sciences. The storage ring is based on a 24-cell double bend achromatic lattice of 561m circumference. The spectral output is optimised for high brightness up to 20keV from undulators and high flux up to 100keV from multipole wigglers.

The organisation currently consists of 150 staff and will eventually grow to some 300. Diamond Light Source is currently in the detailed design, build and procurement phase. Stage 1 of the building work, covering the enabling works, site preparation and foundations, was completed in September 2003. Stage 2, including the buildings and accelerator enclosures, is underway.

Diamond's construction programme has been planned to extremely fine detail to ensure that the first seven beamlines can begin operations in 2007. An additional 15 beamlines will be constructed around the machine at a rate of 4 to 5 per annum from 2007 onwards. The programme is currently in its most intense period, geared to secure early access for Diamond's engineers, technicians and scientists.

Figure 1 – Diamond from the air in Sept 2004

3. SURVEY AND ALIGNMENT GROUP

The Diamond Survey and Alignment Group currently consists of a Group Leader, Survey Engineer and 4 Survey Technicians, although this number will decrease in the later operational phase. The bulk of the team was assembled over the last 9 months being recruited from the surveying, mechanical engineering and aerospace industries. The group is responsible for ensuring the Diamond accelerators and beamlines are installed and maintained within the design alignment specification.

Early activities focused around the development of a survey and alignment strategy for the Diamond machine and beamlines. This included survey network design, development of a machine installation philosophy and participating in the overall machine and beamline design process. To facilitate this process a number of accelerators around the world were visited and engineers from those facilities provided invaluable advice during this period.

Over the past 9 months the team have been heavily involved on the construction site measuring and qualifying the primary survey network and establishing reference datum points throughout the accelerator tunnel networks. Machine installation is about to commence.

4. SURVEY NETWORKS AND REFERENCE SYSTEMS

As with all large scale metrology tasks the geometry and accuracy of the survey networks directly affects the accuracy that can be achieved for subsequent alignment tasks. In areas of restricted access, typical on accelerator builds, where sight lines are heavily constrained, it is important that the design and installation is qualified before building work commences. As well as designing a network and alignment strategy that will deliver to functional targets consideration must also be given to optimise the efficiency of the measurement process. The accelerator is being built to be used therefore survey resources need to be applied in a manner that is conducive with the minimisation of downtime to the user community.

4.1. Primary survey network

The Diamond primary survey network consists of a central pillar and 7 peripheral pillars on a radius of 159m, each concrete pillar being set on a 12m deep pile. The pillars are fitted with survey monuments enabling force centring of theodolites and total stations.

The network was first measured in Sept 2003 using a Leica TDA-5005 total station measuring to a corner cube reflector. At the time, sight lines were unobstructed therefore from each monument all other monuments could be observed. Fig. 2 identifies network geometry and applicable error ellipses.

During the initial building phase it was important to qualify the network geometry on a regular basis. The network was used extensively by the building contractors when setting out the tunnel walls and by the Survey and Alignment Group setting out reference points in the floor slabs for subsequent phases of the project. It was not possible to pour the whole synchrotron floor slab prior to erecting the walls therefore the reference points had to be set out intermittently over a 5 month period.

Over this 5 month period the network was measured on a monthly basis. The global position of all the monuments remained stable within ± 1 mm, the uncertainty growing to ± 0.4 mm at the end due to ever diminishing lines of sight. The network design proved adequate however, additional monuments would have been useful considering the amount of concurrent surveying activities going on during this intense period.

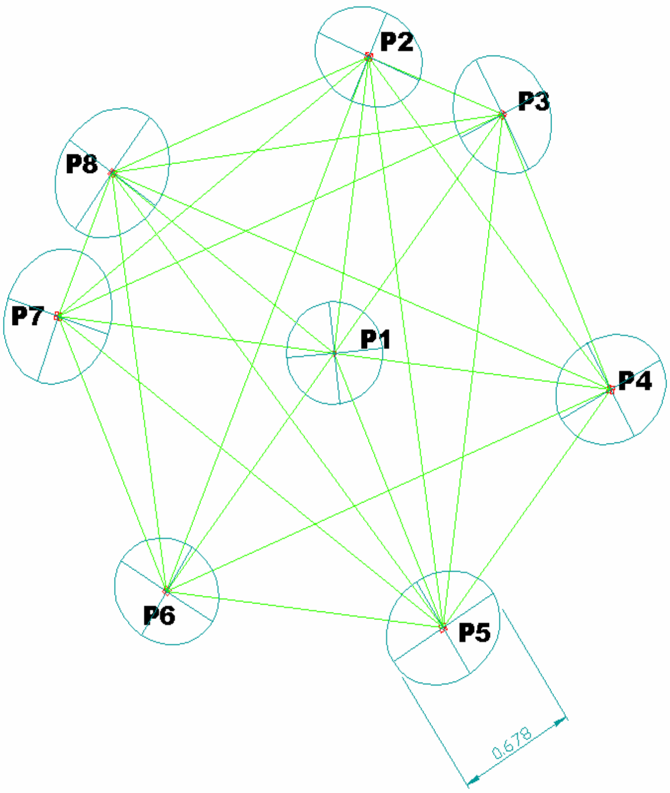

Figure 2 – Primary survey network geometry and error ellipses

4.2. Floor Reference Points

The floor reference points define key co-ordinate references within the tunnel floor slabs for machine and survey network installation. A total of 350 brass pins, Fig 3, were installed in the synchrotron floor slabs, Fig 4. The pins were set out and marked to nominal co-ordinates using a Leica TDA-5005 total station utilising stakeout software. An RCS 1100 remote control unit proved invaluable during this operation removing the surveyor from the instrument and placing him at the target point where the marking out activity was required.

Figure 3 - Floor Reference Pin

The pins are being used to enable initial machine and beamline layout, and to define the nominal position for the 3 tunnel survey networks.

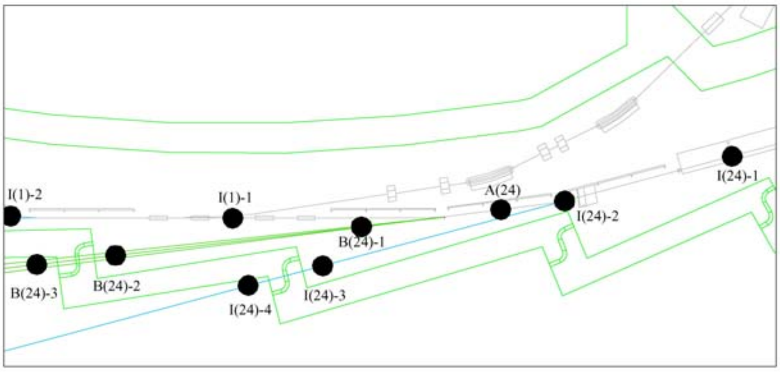

Figure 4 - Floor reference pins within a section of the storage ring tunnel

4.3. Tunnel Survey Networks

The 3 tunnel networks, see Fig 5, are separated by concrete walls, however lines of sight have been maintained at a small number of positions by the provision of survey ports. There are 2 ports linking the storage ring and booster tunnels and 2 ports linking the booster and linac tunnels. Ports are also provided to maintain lines of sight to the centre survey monument from 3 equi-spaced positions in the storage ring tunnel and 1 position within the booster tunnel. Additionally there is a survey port provided in the ratchet wall on the axis of each beamline.

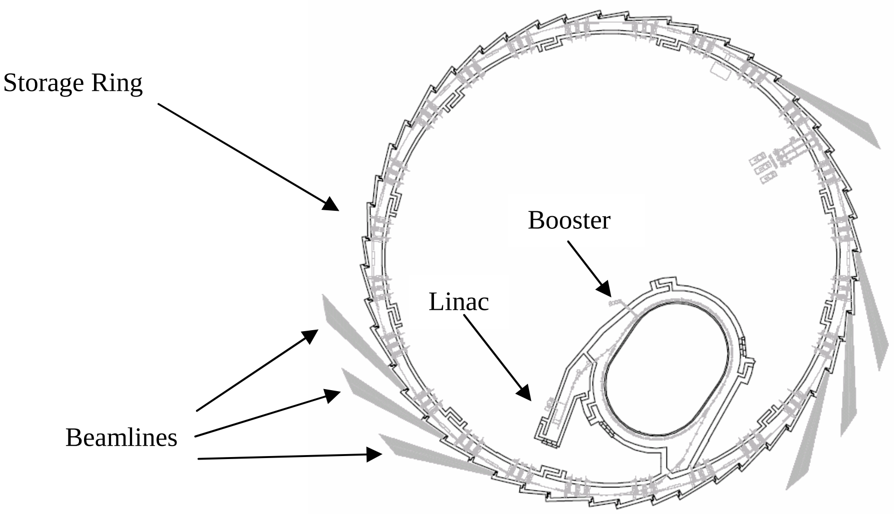

Figure 5 - Synchrotron Accelerator Layout

Each Monument is mounted on a fixed wall bracket, Fig 6 and centred over its respective floor reference pin using a Leica ZNL optical plummet. On completion there will be 49 survey monuments in the storage ring tunnel, 25 in the booster tunnel and 6 in the linac tunnel.

Figure 6 – TDA 5005 total station mounted on a booster tunnel survey monument

In addition to the survey monuments, a network of floor and wall mounted target nests will be provided within the tunnels and in the experimental hall. The floor mounted nests will provide the level datum for all machine and beamline altimetric surveys and the wall nests will improve survey geometry when qualifying the tunnel networks. Additionally they will enable 3-D transformations in areas where laser tracker operations are desirable.

4.3.1. Booster Tunnel Survey Network

The booster tunnel network was installed and measured in August 2004 using a pair of TDA-5005 total stations. This initial survey consisted of measurements from each survey monument to all visible monuments within the network. A least Squares free network adjustment was then carried out to best fit the as-installed monument positions to their design nominal. GCPv1 software provided by the ESRF was used for this operation determining the planimetric co-ordinate data. Fig 7 details the deviation from design co-ordinates achieved for the monuments. This data provides a good indication of the stake out accuracy to be expected for the survey reference pins. Fig 8 illustrates the uncertainty of the network.

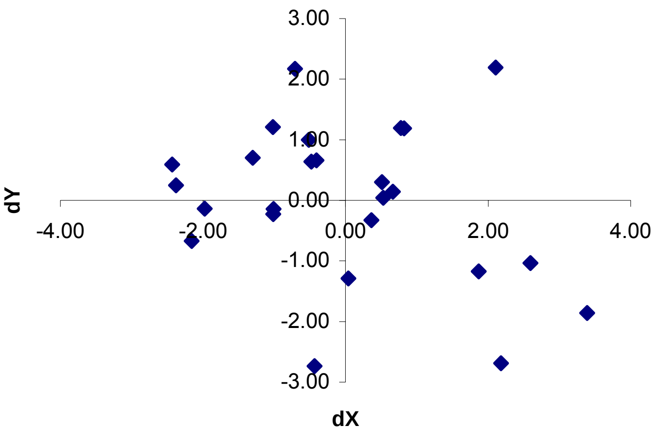

Figure 7 - As-installed monument positions compared to design co-ordinates (mm)

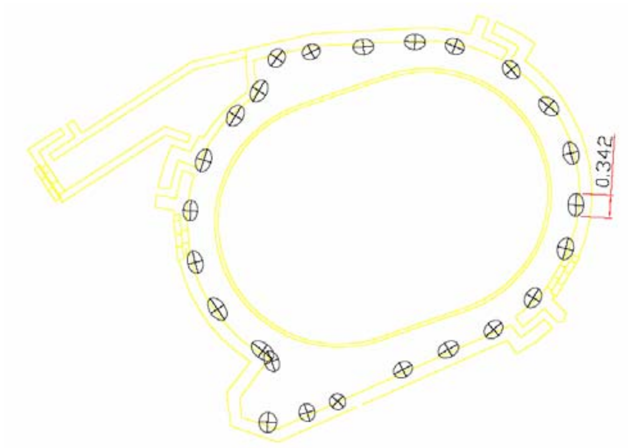

Figure 8 – 95% Absolute Error Ellipses for Booster Monument Co-ordinates

A total of 20 floor target nests have been installed and measured for level within the booster tunnel. A Trimble dini 12 digital level measuring to a 2m invar staff was used for this purpose. The instruments internal collimation error correction was used supplemented by collimation error correction techniques developed at the ESRF [1]. A closure error of 0.06 mm was calculated for the levelling run.

4.3.2. Storage Ring Tunnel Survey Network

The installation of the storage ring survey network is currently ongoing and should be complete by the end of October 2004. In general the survey monuments will be positioned on a radial line intersecting the centre of each Insertion Device straight and the centre girder of each cell. Additionally there will be 96 wall nests mounted on the ratchet wall acting as fixed target points for network measurement. The network survey will include 8 target nest measurements from each survey monument amounting to a total of 384 observations. Fig. 9 illustrates a section of the survey to be undertaken.

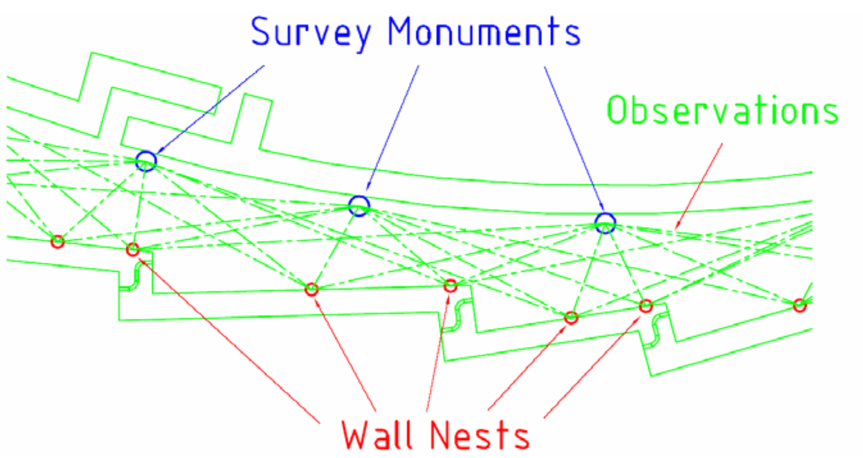

Figure 9 - Sample representation of the storage ring tunnel network survey geometry

5. MACHINE INSTALLATION

The main magnets and vacuum vessels of the Diamond accelerators will be pre-aligned on girders prior to installation in their respective tunnels. The booster girder assemblies are being supplied as a turn key project with all pre-alignment tasks being carried out by the supplier. The storage ring girders are to be assembled on site by DLS personnel supported by contract labour.

5.1. Storage Ring pre-alignment

Each cell consists of 3 girders which provide the local alignment features for the magnets. The girders come in 2 lengths ~ 5.9m and 4.3m, the longer girders accommodating the dipole magnets.

Each magnet will be supplied with a set of keys and shims which align the magnet onto its magnetic centre with reference to the girder. Survey points will be provided on top of the magnets which will be valued by the supplier with reference to the magnet's magnetic axis controlling the planimetric and altimetric alignment. Kinematic mounting points will be provided to enable roll axis measurement of each magnet using a Nivel inclination sensor.

Each girder assembly shall be surveyed to ensure the local alignment between magnets has been achieved. This survey will be carried out using a Faro laser tracker running Spatial Analyzer (SA) software. To optimise survey accuracy multi-station measurements will be employed; all measurements will then be combined using SA's unified spatial metrology network. This process will provide best fit co-ordinate data, supported by uncertainty field analysis for all points within the survey and network residuals for each instrument.

Once the as-built position of the magnets has been determined, a local girder co-ordinate system will be established co-incident with the best-fit magnetic axes of the magnets on the girder. A survey monument will then be positioned at each end of the girder directly above the girder's magnetic axis. These monuments will become the alignment reference for in-tunnel installation and provide a force-centring interface for front end and beamline alignment.

Using the simulation function within SA, a 3-D analysis has been carried out of the proposed survey geometry for the girder survey. Fig. 10 illustrates the survey geometry and portrays the uncertainty fields as point clouds around each point representing the magnitude of error. As well as providing point uncertainty data, the software also provides residual data for the individual instruments within the network. If an instrument is performing badly within the network then its measurements can be excluded or additional measurements added. Where an instrument is performing outside of its recommended parameters then this functionality can help to identify such a problem.

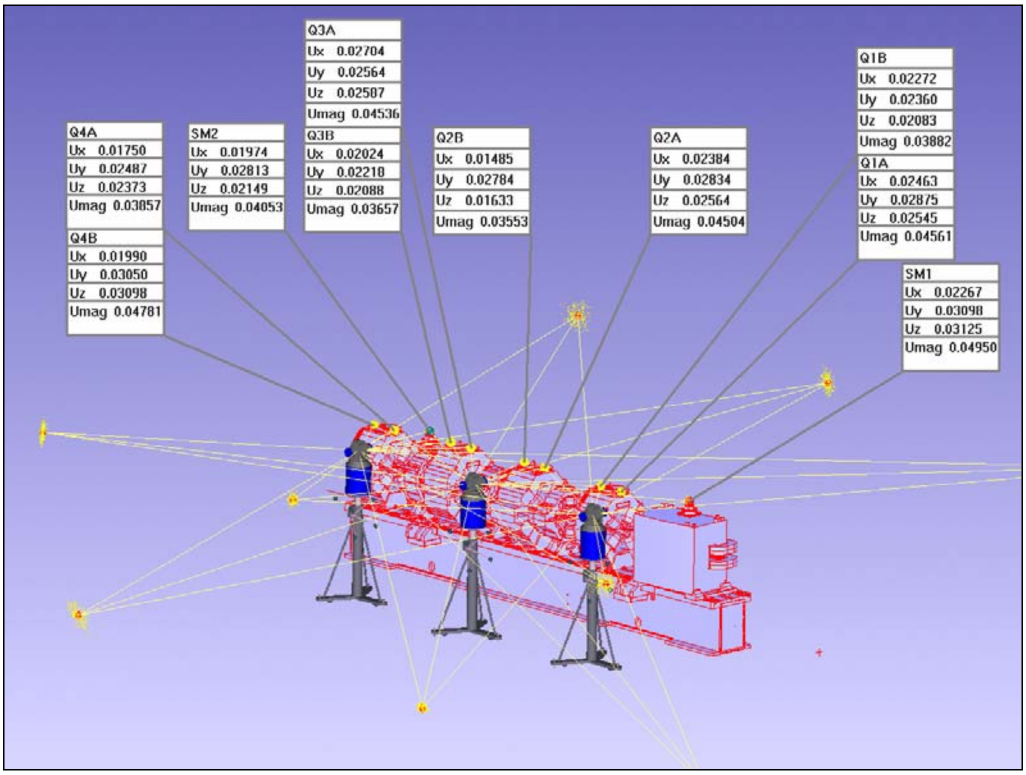

Figure 10 – Graphical representation of Spatial Analyzer survey simulation

5.2. Storage ring installation

The initial girder alignment will be provided by baseplates aligned with respect to the tunnel survey network and levelled to a local height datum. Once the baseplates have been aligned a grout of 25mm minimum thickness will be poured to fill the cavity beneath the plate.

Each plate is fitted with 2 dowels which mechanically align the girder pedestal. On top of the pedestals are keyways which in turn align the girder mover system. Once the baseplates and pedestals, together with the mover system, have been installed, the girder can be lowered into position. The girder will then be surveyed with respect to the local network and its position adjusted as required to enable the vacuum vessel connections to be made.

Once all girders are installed a complete storage ring survey will be carried out and a free network adjustment calculated against nominal co-ordinate data. The girder mover control system will then be used to move the girders to their required position.

The storage ring survey has been simulated to determine the relative and global uncertainty that can be expected from the proposed observation geometry using a TDA-5005 total station. Generally, each Girder's Survey monuments will be observed from 6 instrument stations equating to a total of 864 observations. This is the case for all positions except those immediately adjacent to Insertion Devices where observations have had to be omitted due to blocked lines of sight. Where this occurs there is a slight degradation in longitudinal control of ~ 20 μm, radial control is maintained.

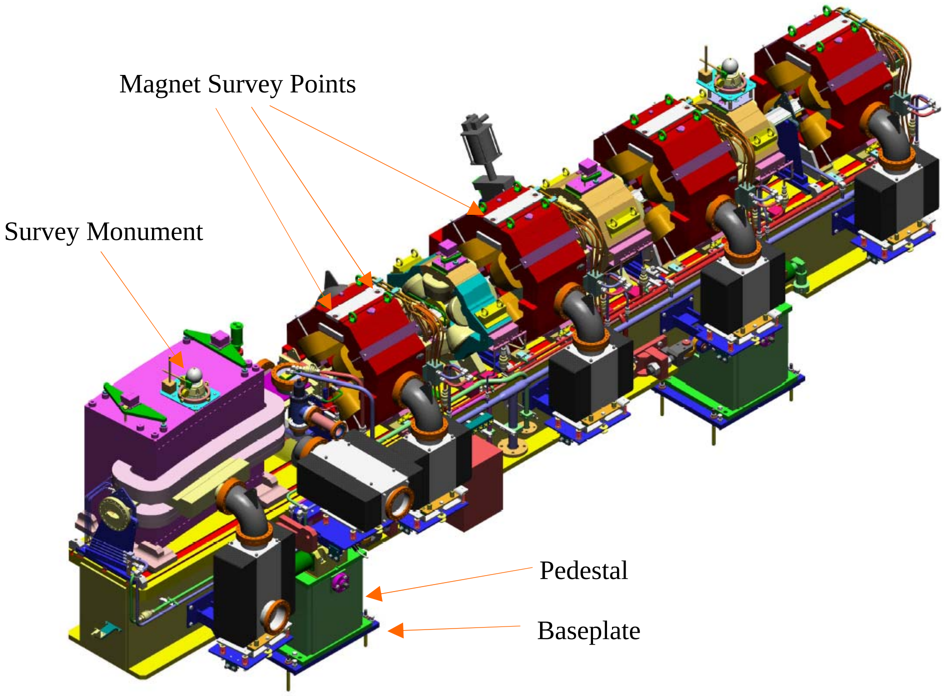

Figure 11 – Storage Ring Girder Type 2

The following 2 graphs Fig. 12 & 13, detail the predicted measurement uncertainty for the storage ring survey. The measurement simulation was carried out using GCPv1 software provided by the ESRF. Instrument uncertainties of 0.15 mm for distance measurement and 3 dmg (4.7µrad) for angle measurements were used in the simulation. It is planned to introduce distance error corrections for all machine surveys. Correction values will be provided following an enhanced calibration on the ESRF calibration bench [2].

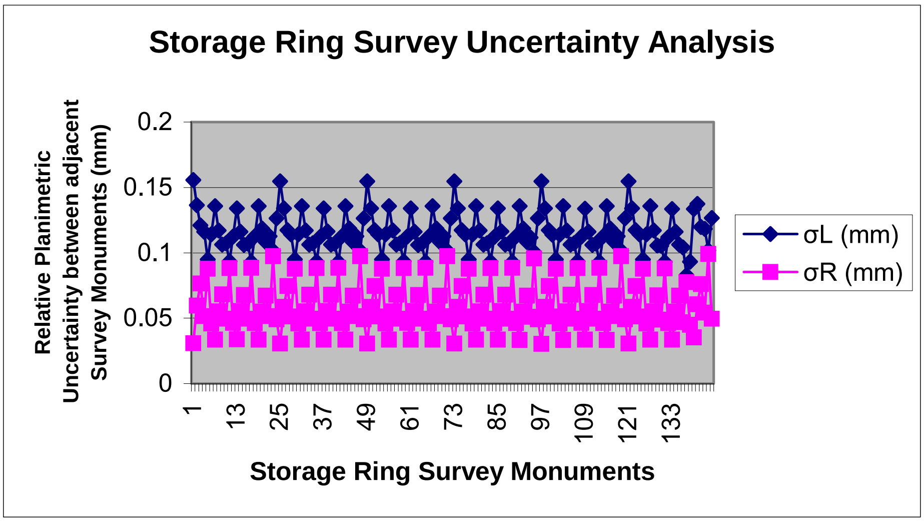

Figure 12 – Storage Ring Planimetric Relative Alignment Uncertainty

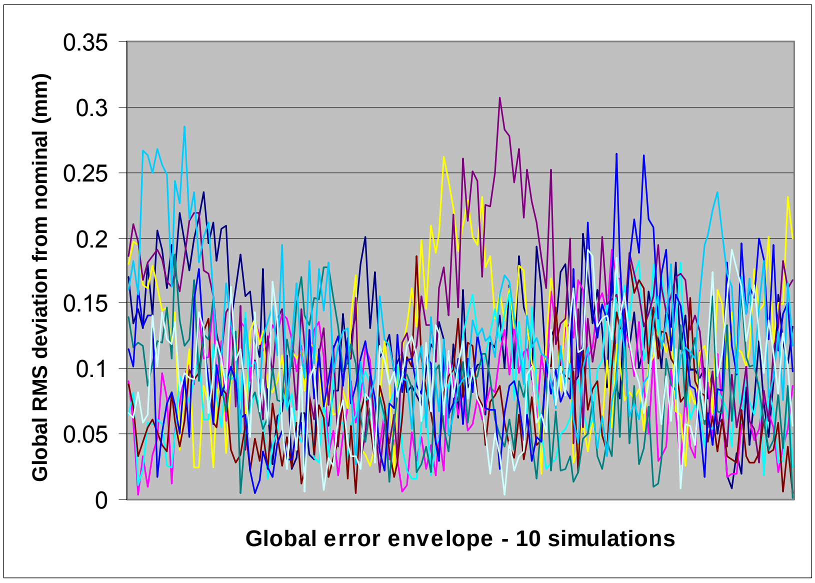

Figure 13 – Storage Ring Planimetric Global Alignment Uncertainty

6. CONCLUSION

Diamond is now at a key transitional stage moving from construction activities through into machine installation and commissioning. The booster network is installed and qualified and the storage ring network installation is at an advanced stage, both networks are performing as predicted. Future work activities include the pre-alignment of storage ring components and the installation of the machine and phase 1 beamlines. The development of survey and metrology techniques during this next phase of the project provides exciting challenges for the DLS Survey Team.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] N Levet, D Martin, Optimisation of the ESRF storage ring level survey and network, Proceedings of the 7th International Workshop on Accelerator Alignment, Spring-8, 2002

[2] D Martin, Instrumentation and Calibration at the ESRF, Proceedings of the 7th International Workshop on Accelerator Alignment, Spring-8, 2002