DIAMOND STORAGE RING REMOTE ALIGNMENT SYSTEM

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Abstract

Diamond is a 3GeV, 3rd Generation Synchrotron Light Source currently under construction as part of the Harwell Science and Innovation Campus, Chilton, Oxfordshire. The 24 cell Diamond Storage Ring is 561.6m in circumference and is mounted on 72 support girders, the largest of which are 6m long and weigh 17 Tonnes. Each girder can be remotely positioned in 5 axes using a system of motorised cams. This system has been designed to enable the future remote realignment of the Storage Ring using beam based alignment techniques. The system is described in detail including the mechanical and electrical components of the system as well as a description of the alignment algorithms employed and how these have been incorporated into the control system.

INTRODUCTION

To facilitate accurate magnetic alignment in the Diamond storage ring, all magnets have been mounted on 72 support girders of 3 types, the largest of which are 6m long and weigh 17 Tonnes [1]. The design for the Diamond storage ring girders has been developed from the solution adopted for the SLS, which in turn built on previous work on remote alignment at SLAC [2, 3]. The magnets are located into reference grooves on the girder face and individually shimmed to achieve a relative transverse alignment of ±0.1mm along the girder length. The girders rest on four motorised cam assembly blocks, and can be aligned with five degrees of freedom using the five motorised cams to a survey tolerance of ±0.1mm. This system forms a “cone, groove and flat” kinematic mount, in which the groove is split with one face on either side of the girder.

Using a right-handed Cartesian coordinate system in which x points radially outwards, y is upwards and z follows the beam direction, the degrees of freedom controllable using the cams are:

- 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)

The surge of each girder (translation along z axis) is altered manually.

ALGORITHMS FOR GIRDER ALIGNMENT

Alignment of the girders is performed remotely through simultaneous adjustment of each of the five motorised cams, a unique combination of which exist for each girder orientation. Camshaft rotation angles are calculated using the equation [4]:

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

where $ø$ is the camshaft rotation angle with respect to the x axis, ψ_0 is the angle between the x axis and a vector pointing from the cam centre to the girder contact point, b is the distance between the centre of the cam and the centre of the camshaft and the constants m are distances between the camshaft centres and the point of origin for the electron beam axis at the centre of the girder.

The range of motion available to the girders is given in table 1. Note that the full range for each degree of freedom cannot be reached simultaneously, but that the available range of motion comfortably exceeds that required for girder alignment.

Table 1: Range of motion for each girder type.

	Short Girder	Long Girder
Sway (mm)	±7.07	±7.07
Heave (mm)	±5.00	±5.00
Pitch (mrad)	±4.16	±3.03
Yaw (mrad)	±5.89	±4.28
Roll (mrad)	±7.02	±7.02

HARDWARE DETAILS

The 5 cam assemblies each consist of an eccentric cam mounted on a shaft driven by a motor and gearbox assembly. The camshafts are built into 4 mover blocks, one of which contains a double cam arrangement and each is positioned to support one corner of the girder. An example mover block is shown in figure 1.

Figure 1: Example cam assembly showing point of contact with girder.

After initial testing of a prototype system, some modifications were required: The cam follower or ‘V’ block for the double mover had to be given a rotational degree of freedom to prevent it being raised vertically by girder yaw. The mechanism is illustrated in figure 2.

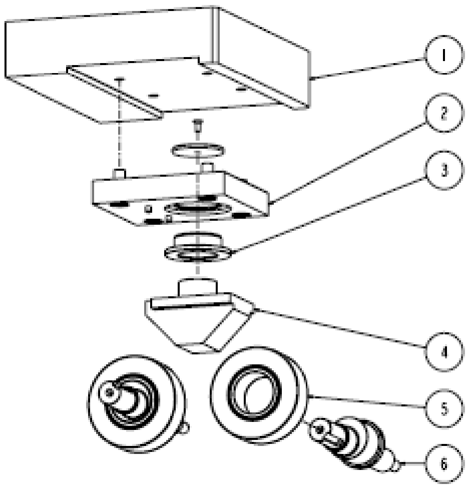

Figure 2: Exploded view of double mover cam.

Item 1 is part of the lug attached to the girder, item 2 is a longitudinal sliding plate, item 3 is the bearing, item 4 the cam follower, items 5 and 6 are the cams and drive shafts. Each cam follower must have a longitudinal sliding degree of freedom to prevent surface gauling at the line contact areas between cams and cam followers. Surface gauling was most noticeable after repeated pitch cycles before the modifications were included.

The accuracy of the positioning system was also found to be sensitive to the girder mounting pedestal design. A significant improvement was achieved by the inclusion of a tie bar between the pedestal uprights. The increase in stiffness improved the pedestal deflection under load; if the tie bars were not present any rotation of a cam produced significant movement of the pedestal as well as the girder, which reduced system accuracy.

The motor and gearbox assembly is made up of a ROK311S DC servo motor coupled to a 15:1 ratio worm-drive gearbox, eliminating back driving and enabling the system to hold position when powered down. This assembly is then coupled to the camshaft via a 320:1 NEUGART PLE120/115-320 planetary gearbox. The output speed range of the assembly is 0.1 – 0.5 RPM, and half a revolution of the shaft provides the maximum linear displacement of ±5mm. High resolution position monitoring for the rotating cams is achieved by the use of TR Electronic CS-58-S SSI multi-turn absolute rotary encoders, fitted to the end of the shaft after the cam mover itself. The encoders have a resolution of 32768 counts per revolution, equivalent to 0.19 mrad steps.

A measurement of relative displacement between neighbouring girder ends and to the primary BPM stands in the straight sections is achieved using pairs of Heidenhain ST1200 length gauges at each position. These are mounted orthogonal to each other to monitor the relative positions in both vertical and lateral directions.

Freedom to move girders independently is provided by the inclusion of inter-girder vacuum vessel bellows and bellows between dipole vessels and front ends. Limit switches protect the integrity of the bellows in both vertical and lateral directions by limiting relative vacuum vessel displacement to ±2 mm. The limit switches are positioned at the intersection of each girder and between girder and primary BPM stands. Additional protection is provided for the vacuum vessels by motion stop buttons that interrupt the power supply to the motors under emergency conditions in order to disable all motion. These buttons are positioned on each girder and on each control rack.

CONTROL SYSTEM

The girder control system consists of 24 racks, each of which is responsible for the three girders within one cell. Every rack holds a dedicated EPICS IOC based on a MVME5500 processor, two OMS58 motion controllers and various VME based I/O cards.

The operator interface consists of several levels, starting with an overview of the technical area indicating the ready status of each girder. Selecting an individual girder from this panel then allows the operator to control each degree of freedom independently. Even deeper levels of the operator interface offer extensive diagnostic information, individual cam controls and servo tuning parameters for engineering work. Images for the top two levels of the interface are shown in figure 3.

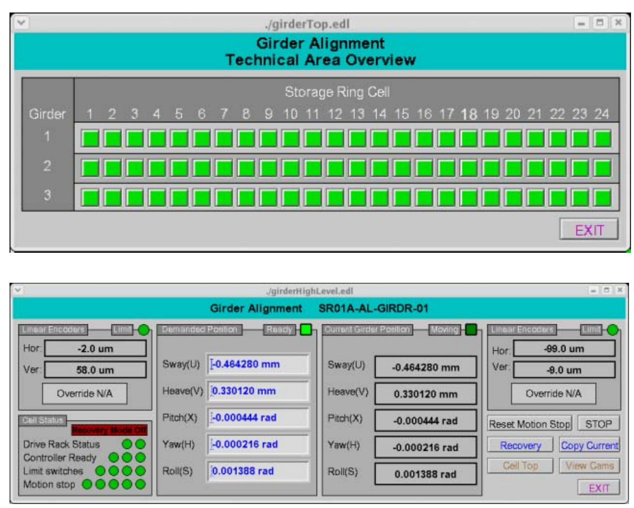

Figure 3: Operator panel indicating ready status for each girder (top) and panel for girder positioning (bottom).

GIRDER ALIGNMENT SURVEY

Following girder installation and connection of the vacuum bellows, the first global storage ring survey was carried out in May 2006.

Each girder's planar position is defined via two survey monuments positioned at each end of the girder, and girder roll is measured using a tilt sensor. The position of the machine was measured from 48 survey stations using a TDA-5005 total station, and following a least squares adjustment of the network, the radial uncertainty value for all girder survey monuments within the network was calculated to be between 25 and 71µm. The level survey consisted of a 2-way closed loop levelling run along the 561.6m storage ring using a Trimble Dini 12 digital level measuring to an invar bar-coded staff. The run closed to within 100µm i.e. < 1.5µm per girder. Roll measurement of each girder completed the survey to micron resolution.

Following the survey all data was entered into a processing spreadsheet which calculated the girders spatial position in terms of pitch, yaw, roll, heave, sway and surge, and thus the input data for the mover system was established. From this data, a selection of the girders were identified as requiring realignment with a high priority, the data for which is shown in figure 4, and the corresponding data for post-realignment in figure 5. As can be seen, the girder mover system was able to re-position the girders to the required alignment in a single iteration and to within the specified alignment tolerance and global accuracy of the survey network.

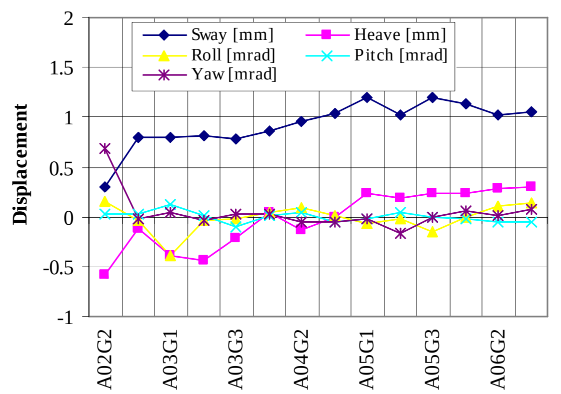

Figure 4: Post-construction survey results. Data shown for girders selected for priority realignment.

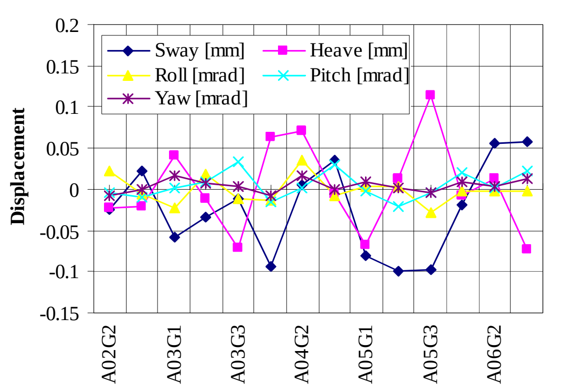

Figure 5: Survey results for selected girders following realignment using remote alignment system.

FUTURE PLANS

Integration of the girder control system with the EPICS network allows the future realignment of the storage ring girders using beam-based techniques.

Through changes to the girder and hence magnetic alignment, the goal is to find the combination of girder orientations that minimise the closed orbit amplitude at the BPMs. Treating the girders as a series of pseudo-corrector magnets, a sensitivity matrix can be built up giving the electron beam response to changes in girder sway, heave, pitch and yaw.

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} M_{Xu} & M_{X\eta} & M_{Xv} & M_{X\chi} \\ M_{Yu} & M_{Y\eta} & M_{Yv} & M_{Y\chi} \end{pmatrix} \begin{pmatrix} u \\ \eta \\ v \\ \chi \end{pmatrix}$$

Using singular value decomposition [5] to invert the resulting sensitivity matrix then allows the desired combination of girder alignments to be found. Since the Diamond storage ring has a total of 168 BPMs and only 72×2 girder alignment variables in each plane, the resulting problem is over-constrained, and the solution that minimises the closed orbit error at the BPMs will be found.

Girder realignment using this technique is expected to significantly reduce the requirements on corrector magnet strength. By varying girder roll it is expected that emittance coupling of the beam can be locally controlled in a similar fashion.

CONCLUSIONS

Following girder installation, the alignment system has been used to align each of the 72 storage ring girders to the global survey network, and was found to align the girders to within the survey tolerance. Using the system, the alignment process has proved to be straightforward, with individual girders taking of the order of half an hour to align. Integration of the system with the EPICS network and suitable girder orientation diagnostics also allows for the possibility of girder alignment to be carried out from the control room, and also to be carried out using beam-based techniques.

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