# GIRDER ALIGNMENT IN THE DIAMOND STORAGE RING

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*Abstract*

A model of the Diamond Storage Ring describing the misalignment of its 74 girders in terms of displacements and rotations is used to predict the orbit distortions and corrector magnet strengths needed for a zero orbit. Using the data from a survey we compare the effect of a pure magnet misalignment with the natural orbit of the machine. Tests with displaced girders meant to produce a reduction in corrector strength are introduced. Comparison with data obtained from the actual move of the girders are presented and discussed.

## INTRODUCTION

Diamond is a 3rd generation synchrotron light source, fully operational since 2007 [1]. It features a beam of 3 GeV with a typical 2.7 nm emittance and is presently operated in a low coupling mode (0.3 %) at a current of 300 mA. The initially six-fold symmetric 24 cell structure with Double Bend Achromats (DBA) sitting on girder triplets has been modified with the introduction of double mini-beta sections in straights 9 and 13, which required two extra mid-straight girders hosting quadrupole doublets to match the new optics, for a total of 74 girders in a 561.6 m long circumference [2].

Using survey data taken between January 2012 and January 2013 we study the effect of orbit distortions generated by misalignment and predict the change in corrector strength due to girder moves.

We report on some actual tests done on the machine, both in the vertical and in the horizontal plane and suggest a procedure for the alignment of the storage ring.

## SURVEY

Most of the magnets in the Storage Ring (SR) are mounted on three types of girders that also host beam position monitors (BPMs) and corrector magnets (CMs) embedded in the sextupoles. Each cell has two primary BPMs, mounted on the floor and therefore decoupled from the nearby girders. Girder positions can be surveyed by means of monuments mounted at the edges of every girder (see Fig. 1). In a typical survey, both planimetric (xy) and altimetric (z) views are provided, allowing a comparison between the actual monument positions and the design configuration. The instrumental precision on monument positions varies along the ring, with typical figures of 100 $\mu$m for the horizontal plane and 50 $\mu$m for the vertical one.

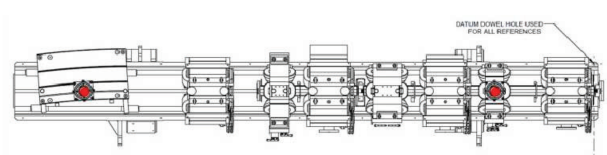


Figure 1: Top view of a standard girder-2. The red dots mark the positions of the monuments used in the survey.

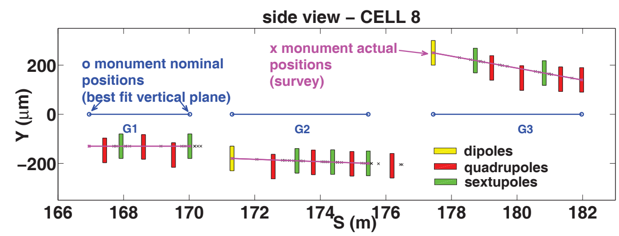


Figure 2: Close-up of the vertical view for cell-8, showing the surveyed magnet displacement for dipoles (yellow), quadrupoles (red) and sextupoles (green). Alignment errors relative to the girder are available for quadrupoles. The magenta lines connect the two survey monuments.

## MODELLING GIRDER MOVES

Magnet displacements introduce dipole components altering an otherwise perfect orbit. Corrector magnets are used to recover this zero closed orbit and the generated CM pattern is a signature of the variations from the design machine. To check if magnet displacements are accountable for the observed CM pattern, we have introduced girder moves in the AT model [3] of the Diamond Storage Ring. Figure 2 displays the vertical girder displacement for cell 8 in the vertical plane. Quadrupole alignment errors with respect to the girder are also included [4].

### *Equilibrium Orbit*

The simple girder moves, as described in the survey, cannot give a satisfactory prediction of the equilibrium orbits in the machine (Fig. 3). For the horizontal plane, a remarkable agreement is found for 2/3 of the orbit, leaving the region between S=300 m and S=500 m unexplained. In the vertical plane the modulation induced by girder displacements shows a general agreement both in phase and spatial frequency, however the strong suppression in amplitude remains unclear. In order to understand if survey instrumental uncertainties can be accounted for this effect, a sample of 500 machine configurations was generated by introducing gaussian perturbations to monument positions with a $\sigma$ equal to the known instrumental errors. Figure 3 shows



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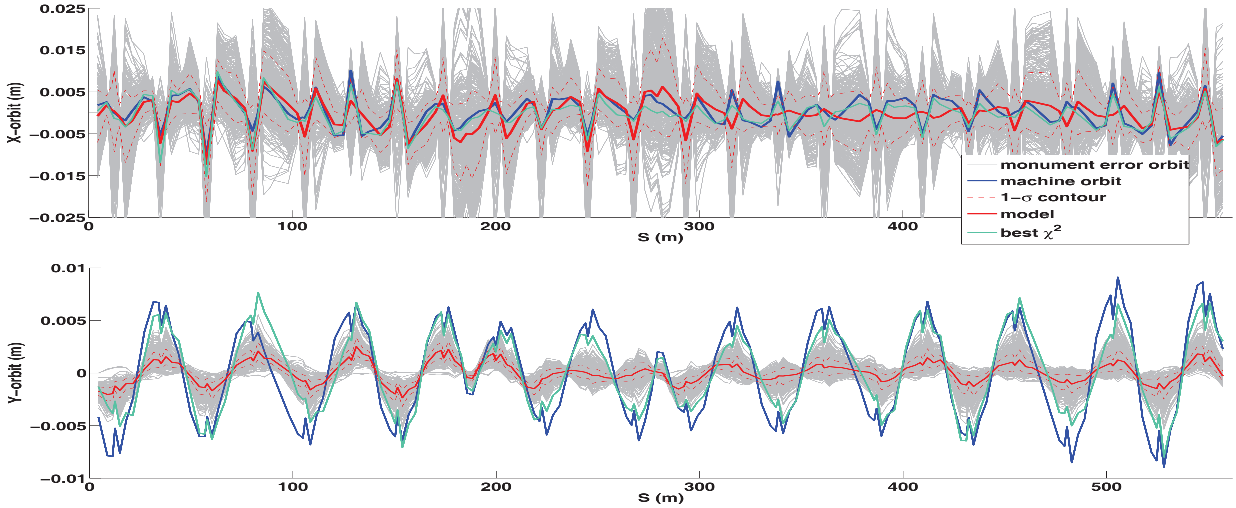


Figure 3: Expected natural orbits from variations in monument positions due to survey instrumental errors for both the planimetric view (top) and the vertical view (bottom).

the resulting 500 orbits (gray) together with the solution corresponding to the surveyed monuments (solid red) and the equilibrium orbit from the machine (blue). The dashed red line is the 1-$\sigma$ orbit envelope from the simulated sample of machine configurations. A $\chi^2$ search through the sample is performed to find the orbit closest to the one in the machine (green line). We find that in the horizontal plane instrumental errors may account for the observed orbit discrepancies (best match solution well within the 1-$\sigma$ envelope). In the vertical plane the best match solution is outside the 1-$\sigma$ envelope. For this case, the corresponding girder positions are in general not too far from the surveyed values, with the exception of few outliers, as shown in Fig. 4 for the girder pitch angles. As a general conclusion of this part, it is felt that pure girder movements might not be the sole responsible for the actual equilibrium orbit and for the corresponding CM pattern. On the other hand, controlled *changes* in the position of a girder should produce well defined changes in the orbit and hence in the corrector magnets. This will be the focus of the next sections of the paper.

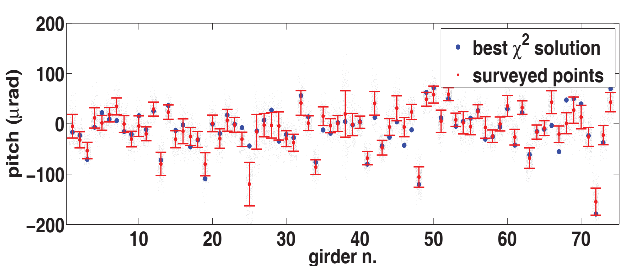


Figure 4: Girder pitch angles. Survey points are shown in red, together with the error bars from instrumental measurements of the monuments. The blue dots show the solution whose vertical orbit better matches the one in the machine.

### *Prediction on Corrector Strengths*

The non-zero equilibrium orbit at the BPMs generated by magnet displacements can be fed into the orbit correction algorithm, usually running online, to calculate the CM set bringing the orbit back to zero at the BPMs. The AT algorithm is based on the usual BPM Response Matrix and finds the correcting CM set via an iterative procedure.

## TESTS ON THE MACHINE

A girder move is achieved by adjusting the position of five independent motorised cams that resolve into the main spatial degrees of freedom (sway, heave, roll, yaw and pitch). The EPICS based motion control system can, in principle, be operated from the control room. However, at this early stage of operation every move is performed under local control via a laptop and a portable rack containing the motion control components (motion controller and amplifiers). In a typical girder move session, positions and inclinations are also monitored by the survey team, enhancing the confidence in the measurement. A protection system, based on pairs of linear travel sensors, has been implemented to ensure that any possible motion control failure will not result in damage to the inter-girder bellows. If possible, before and after the move, a Beam Base Alignment (BBA) is run in order to align the BPMs to the quadrupole centres and avoid systematics in the CM values. So far in Diamond, we have tested the effects of three girder moves, one in the horizontal plane and two in the vertical plane.

### *Horizontal Move*

On December 4$^{th}$ 2012, we moved girder 2 in cell 3 (C3G2) by a horizontal sway of +324 $\mu$m. This choice was motivated by the zero impact of the move over nearby beam lines and by the attempt at reducing gaps between adjacent girders with a single move (see Fig. 5).


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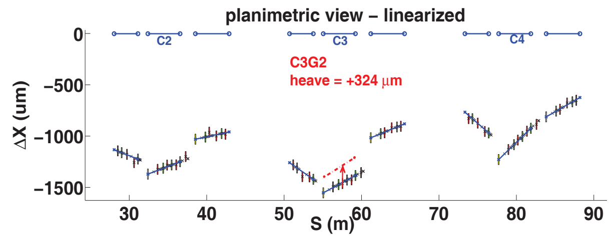


Figure 5: Planimetric view of the zone around cell 3. The sway of +324 $\mu$m for girder 2 is shown in red.

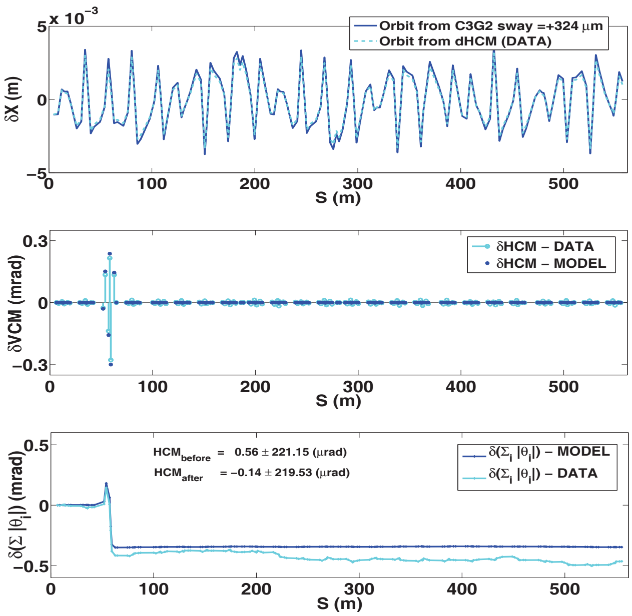


Figure 6: Effects of the horizontal girder displacement as seen in the machine (cyan) and in the model (blue). (Top) Variation in the equilibrium orbit. (Middle) Variation in HCM currents. (Bottom) variation of the integrated CM strength in the storage ring.

The variation in the equilibrium orbit inferred from the change in machine HCM strengths before and after the move, is compared to the one predicted by girder displacement (Fig. 6 (top)). Using the orbit correction algorithm we find the HCMs due to a pure girder misalignment and we compare them to the ones observed in the machine (Fig. 6 (middle)). Both cases show a remarkable agreement. By introducing the integrated CM strength $S_\theta = \sum_{i=1}^{172} |\theta_i|$ we see that a reduction in the corrector strength occurs when inter gaps and angles between adjacent girders are reduced. Fig. 6 (bottom) shows a stepwise localized reduction in $S_\theta$ both in the model and in the machine, with some distributed continuation of the effect in the latter.

### *Vertical Moves*

On February 19$^{th}$ 2013 we moved C20G1 by a vertical heave of +94$\mu$m and a pitch angle of -54$\mu$rad. This partial re-alignment of cell 20 was meant to reduce the golden offsets at the primary BPMs before and after the I20 insertion device, used to correct the inclination of the photon beam. The move proved to be successful in that I20 measured a change in the photon intensity scan consistent with our predictions. However, the lack of a BBA measurement prior to the move prevented us from having a clear comparison for the VCM variation.

This was overcome on April 30$^{th}$ 2013 when girder C8G2 was moved vertically by +197 $\mu$m, with BBA measurements taken both before and after the moving session. The effect on the correctors in cell 8 is shown in Fig. 7, where it can be clearly seen how BBA calculations have to

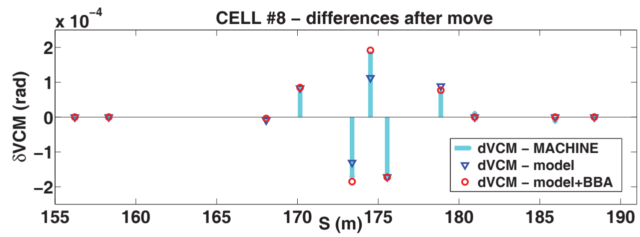


Figure 7: Variation in the vertical correctors of cell 8 after girder 2 heave of +197 $\mu$m. (Cyan) data, (blue) orbit corrections with simple girder move model, (red) orbit corrections with the effect of a BBA measurement in the simulation.

be introduced in the model too, in order to match predictions with data.

## CONCLUSIONS

Thanks to the girder move tests we have reached a significant degree of confidence both on the operational point of view and in the comprehension of the effects on the machine. For the next future plans are set to control three girders at a time (cell), considerably reducing the time spent for a move with a view to a staged re-alignment of the storage ring. When considering a global re-alignment of the machine, the impact on the nearby beam lines must be minimized. To achieve this so called *transparent* re-alignment we have already defined the vertical plane golden offsets at the primary BPMs, in such way any alteration of the present magnet set-up will have no effect on the beam lines. A similar study is in progress for the horizontal plane.

## ACKNOWLEDGMENTS

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