A STUDY OF GIRDER ALIGNMENT WITH SURVEY MEASUREMENTS IN THE DIAMOND STORAGE RING

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Abstract

Using a model of the Diamond storage ring which includes displacements and rotations of the 74 magnet girders an attempt has been made to correlate survey data with the corrector magnet (CM) strengths required for a zero orbit. We then use the model to deduce the most effective girder movements that will bring about a reduction in corrector strength. We describe the results of these studies, and suggest a test with a deliberately displaced girder and the effect on corrector strengths, aimed at enhancing our understanding of the system.

INTRODUCTION

Diamond is a 3GeV 3rd generation Synchrotron Light Source, fully operational since 2007 [1]. The initially six-fold symmetric 24 cell structure with Double Bend Achromats (DBA) sitting on girder triplets has been recently modified to accommodate low beta sections in straights 9 and 13 [2], which required the insertions of two extra mid-straight magnet supports for a total of 74 girders in a 561.6m long circumference.

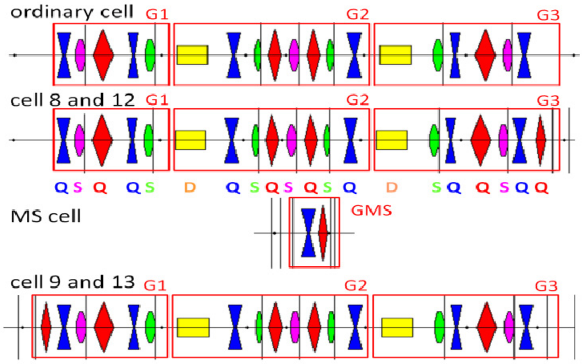

Figure 1: AT model of the DBA cells, with girder triplets G1-G2-G3 hosting quadrupoles (Q), sextupoles (S), dipoles (D) and BPMs (black dots). Also shown is the special Mid Straight girder for low beta sections.

We report on the studies made to understand the link between girder misalignments, as given by a survey of the girder positions taken on January 2012, and the orbit distortions inferred from the values of the 172 corrector magnets distributed along the machine.

SURVEY

In Diamond the magnets of every DBA cell are mounted on three types of girders, which also host beam position monitors (BPMs) and CMs (embedded in the sextupoles). Two primary BPMs are located at the entrance and exit of every cell.

The introduction of low beta insertions required a redesign of sections 8-9 and 12-13 with modified girders for these special cells. Also two short middle straight girders hosting quadrupole doublets were introduced to optically bridge the gaps between the aforementioned cells. The main characteristics of the present girder scheme are reported in Fig. 1. Girder positions in space are surveyed using monuments positioned at the two ends of the girder support (Fig.2).

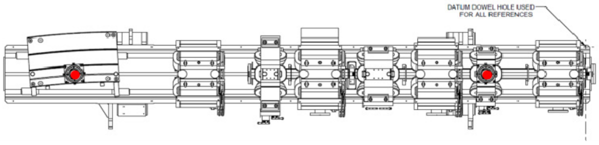

Figure 2: top view of a G2 type girder with the monuments used for the survey (red dots).

The survey provides both a planimetric (xy) and an altimetric (z) view of the actual monuments positions which can be compared with the design configuration. Instrumental precision on the position of the monuments is of the order of 100 µm for the planimetric (xy) survey and of 45 µm for the altimetric (z) survey [3].

MODEL IMPLEMENTATION

It is well known that a magnet displacement introduces multipole components altering an otherwise perfect orbit. The net effect on the machine is a typical CM pattern, aimed at a nearly zero closed orbit. We can therefore check whether deviations from the design machine can be accounted for in the pattern recorded.

In order to do that, an implementation of the girder movements has been introduced in the AT model [4] of the Diamond Storage Ring. Fig. 3 shows the horizontal and vertical girder displacements in the (s,x,y) frame of the model for a section of the ring, together with the CM strengths recorded on February 1st 2012, just after the survey was taken. In this frame s is the main coordinate along the beam orbit, while x and y are respectively the horizontal and vertical deviations from the reference orbit.

Magnets and instrumentation sitting on the girder are moved accordingly, in particular the BPMs belonging to girders that produce a systematic shift in the position measurement.

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If we assume misalignments are the major cause for orbit distortions we should see a correlation between girder actual positions and CM strengths as remarkably shown at the SLS [5]. An example of this is given in Fig. 3(top) where a typical scheme of girder yaw angles, given by the second girder in a cell always pointing outward, seems to result in a characteristic CM pattern. However, this signature is not easily repeated in all the ring and the more irregular position pattern does not give a clear repeated scheme in the CMs, as can be seen for example in the vertical view (Fig. 3(bottom)).

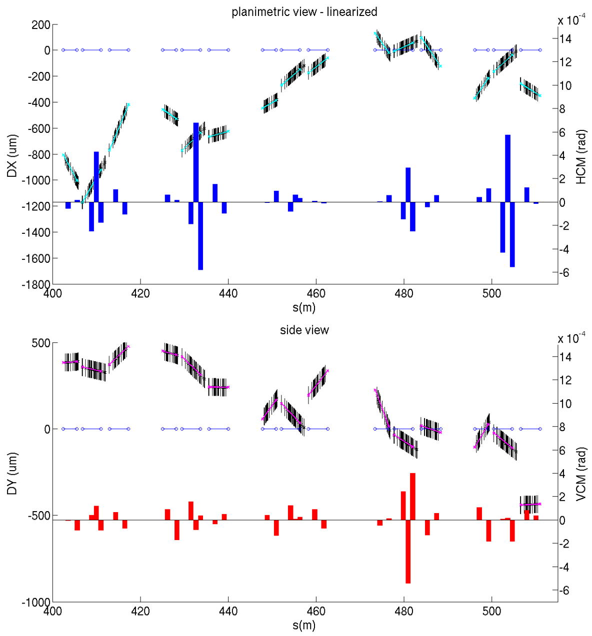

Figure 3: implementation of girder movements in the AT model for the horizontal (top) and vertical (bottom) views. Dark blue segments: original girder monument locations. Cyan/magenta segments: measured girder monuments positions. Black boxes: positions of the shifted magnets in the model. Blue/Red bars: CM strength (rad) from data (note the scale on the right).

The equilibrium orbit can be calculated in two different ways: 1) by feeding an Orbit Response Matrix (ORM) with the recorded CM strengths, 2) by using the latter to modify the correctors in the AT model and then calculating the orbit by means of the AT code *findorbit4* which takes into account also the non-linear elements in the lattice, such as the sextupoles.

We then consider an ideal machine where all CMs have zero strength and move the magnets according to the survey information. Again *findorbit4* produces a new equilibrium orbit at the BPMs which can be compared to the previous ones. Results are summarized in Fig. 4 for both the horizontal and the vertical planes.

We observe a remarkable agreement in the horizontal plane for more than 2/3 of the storage ring. However, part of it remains unexplained and is still an object of investigation. In the vertical plane the modulation produced by pure girder misalignment shows a general agreement in phase and frequency, however the reason for the amplitude reduction by nearly a factor five is still unclear.

In order to better understand the problem we decided to break down the effect of girder movements by adding it cell by cell; in doing so we assume the effect of a misalignment is treatable like a kick in the orbit and all kicks add up linearly. We move all the girders in the n^{th} cell according to survey's prescription, and keep the resulting orbit if it is in phase with the CM-inferred one, discarding a cell if this produces an off-phase orbit. We then proceed with the following cell until completion.

We identify 49 horizontal and 55 vertical girders (out of 74) with 32 girders in common between the two planes, concurring to the formation of a well reproduced orbit as displayed in Fig. 5. Surprisingly a simple choice criterion as the one described, is able to reproduce most of the orbit features, with a stunning result for the vertical case where the initial nearly flat orbit ends up matching the natural one.

We suspect this effect could be partly accountable to the surveying instrumental error (100 µm in the horizontal view, 45 µm in the vertical one) and partly to the magnet

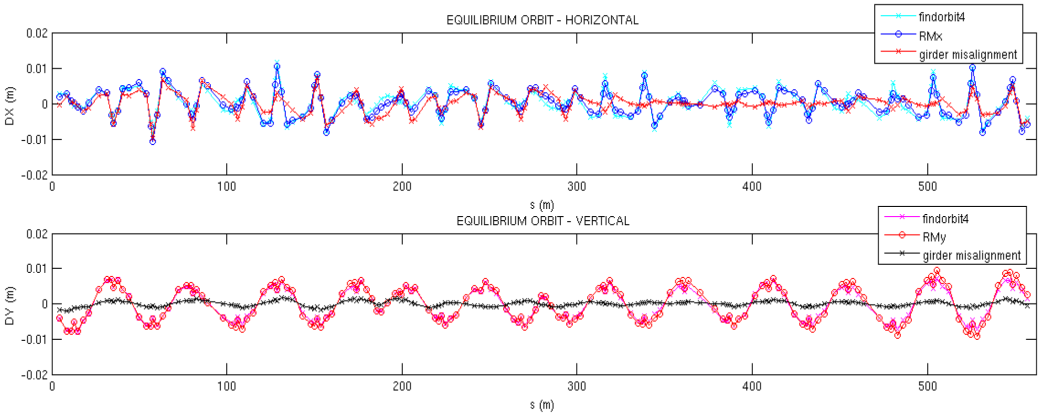

Figure 4: (top) closed orbits for the horizontal plane as inferred from the actual CM pattern by using *findorbit4* (cyan) or a response matrix (blue) and as a result of a pure girder misalignment (red line). (bottom) closed orbits for the vertical plane from the corrector pattern (magenta: *findorbit4*, red: response matrix) and from girder misalignment (black).

position uncertainty along the girder.

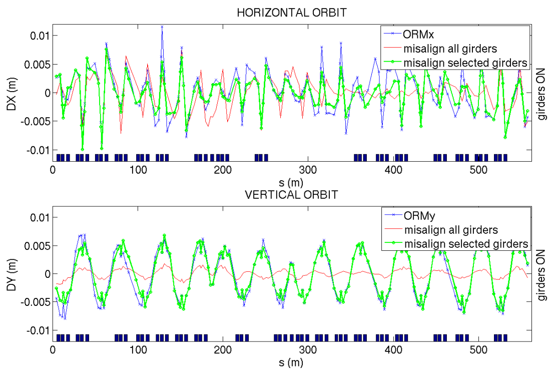

Figure 5: effect of the exclusion of some girder misalignments in the formation of an equilibrium orbit (green line). Blue line: natural orbit inferred from correctors. Red line: equilibrium orbit with all girders moved according to survey. The blue bars at the bottom show the girders taken into account in the calculation.

Instrumental errors have been studied by randomly varying the positions of the girder monuments and generating 100 orbits whose average and standard deviation are compared to the nominal orbit of the beam. In the horizontal view the orbit generated by a misaligned machine is compatible with the actual orbit within the error bars. Vice versa in the vertical plane the discrepancy is still present, as can be seen in Fig. 6.

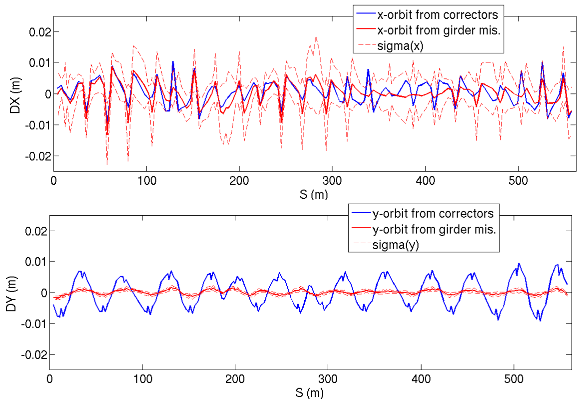

Figure 6: effect of instrumental errors in the survey on the determination of the closed orbit. The average over 100 generated orbits (red line) is compared to the natural orbits (blue line) for both the horizontal (top) and vertical (bottom) planes. A 1-sigma band (dashed red lines) is also shown.

The single magnet positioning error would necessitate a dedicated survey campaign. It should also be noticed how, in the present survey, no data about girder rolls were available. Such effect could introduce further errors in the shape of the orbit too.

CONCLUSIONS AND FUTURE WORK

From what has been said it emerges how our model cannot explain completely the actual equilibrium orbit (or CM scheme) uniquely due to girder misalignments. We plan to evaluate the effect of single magnet displacements in the near future.

However, a good fraction of the ring can be reproduced in the horizontal view and the general oscillation pattern is reproduced attenuated in the vertical view. In order to increase our comprehension of the system we have proposed to move one particular girder to see if the predicted changes in the orbit (or CMs) are actually seen in the machine. According to our AT model, an outward horizontal shift of 324 μm in the second girder at cell 3 (C3G2) should produce a local flattening of the orbit in the region around the girder (presently very spiky) and variations in the CMs up to 30%, an easily measurable effect. The rationale behind this choice is that C3G2 is presently shifted by 1459 μm towards the centre of the ring, while in the new position it would be half way between C3G1 and C3G3, so reducing the step between adjacent girders potentially generating high CM values. In order to be effective and produce a globally flat orbit all the girders should be shifted towards their nominal positions, possibly following an iterative procedure.

Each girder is in principle movable via a remote controlled system [6], however this is presently under a phase of review to verify that commanded shifts are not introducing excessive strain on the beam pipe and bellows connecting girders and straight sections. We plan to use this system as soon as available to verify our model predictions, by checking the effects of a girder position change directly on the CM magnets.

ACKNOWLEDGMENTS

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REFERENCES

[1] R. Bartolini, The Commissioning of the Diamond Storage Ring, PAC 07, Albuquerque, June 2007.
[2] B. Singh *et al.*, Implementation of double mini-beta optics in Diamond Light Source,IPAC2011, San Sebastián, September 2011.
[3] W. Hoffman, private communication.
[4] A. Terebilo, Accelerator Toolbox for MATLAB, SLAC-PUB-8732, May 2001. 37pp.
[5] M. Böge *et al.*, SLS Vertical Emittance Tuning, IPAC2011, San Sebastián, September 2011.
[6] D. Wilson, I. Martin, A. Bell, Survey and Alignment update for the Diamond Light Source, IWAA 2006, SLAC, September 2006.