ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO101

TRANSPARENT RE-ALIGNMENT OF THE DIAMOND STORAGE RING

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Abstract

72 out of the 74 girders on which the Diamond Storage Ring magnets are mounted, can in principle be remotely moved along 5 degrees of freedom (sway, heave, yaw, pitch, roll) potentially allowing a thorough re-alignment of the machine. Previously conducted tests improved our knowledge of the system both in terms of simulations and comprehension of the control system we rely upon. In this report we present the results of more detailed tests which now give us full confidence in our ability to predict the results of any given set of girder moves. We also discuss possible ways of increasing the speed of the procedure, and a strategy to mitigate the impact of girder moves involving nearby beam lines.

INTRODUCTION

As experienced in several light sources (*e.g.* [1]), reducing the vertical misalignments in an electron Storage Ring (SR) like Diamond, is key to reducing the vertical emittance and possibly improving other working parameters such as the lifetime and the dynamic aperture of the machine. Care must be taken when correcting for mechanical misalignments, since every move can have a potential impact on nearby beamlines. After an extensive campaign of girder moves we are proposing a strategy to mitigate the effect of changes in the proximity of working beamlines by making the alignment virtually transparent for beamlines users.

Diamond SR girders show important misalignments both in the horizontal and in the vertical planes, as summarized in Table 1, where data refer to January 2012 survey for the horizontal plane and to January 2013 survey for the vertical plane.

Table 1: Summary of Diamond SR girder positions and tilt angles according to surveys.

H/V-plane	mean	$\sigma_{H/V}$	MAX
sway/heave (μm)	-614/0	331/201	1459/515
yaw/pitch (μrad)	2.9/-11	52/40	117/170

Girder misalignments are one of the most important causes for orbit distortions and can lead to detrimental effects on the overall performance of the machine if left uncorrected. In the Diamond SR, 172 Beam Position Monitors (BPM) and 172 Corrector Magnets (CM) are used to sample the beam displacement around the ring and impart orbit corrections (OC) to restore a zero position at the BPMs. While extremely effective in restoring a high quality beam, OCs come with some side effects:

- CMs do correct the orbit but generate residual dispersion,
- orbit is sent to zero at the BPMs but with non-zero displacement between them.

Dispersion leaks, in particular, are responsible for emittance increase, with an emphasis on the vertical component, whose value is currently set at 8 pm (0.3% coupling). Depending on the displaced element the most diverse effects can turn up: (a) quadrupole shifts generate dipole kicks, (b) horizontal sextupole displacements are responsible for normal quadrupole components and (c) vertical sextupole shifts will excite skew quadrupole components. All these spurious fields turn into an increase in the vertical dispersion (nominally zero) and hence in the vertical emittance, or in tune shifts, increase in coupling and lifetime and reduction of dynamic aperture.

ORBIT CONTROL

OCs for both planes in the Diamond SR are achieved by means of an iterative procedure where the CMs are excited to compensate for the orbit displacements measured in the BPMs distributed along the ring. A pseudo-inverted Orbit Response Matrix (ORM) is used to predict the steerer kicks needed. The same procedure (with minor changes) is adopted both for slow orbit OCs and for the Fast Orbit Feed-Back (FOFB), the latter ensuring sub-micron corrections during normal machine operations. A key point in this procedure is the definition of *zero* at the BPMs, since orbit corrections try to make the orbit displacement null at those locations. In order to make this definition unambiguous, a procedure called Beam Based Alignment (BBA) is adopted which defines as zero of a BPM the orbit passing through the *magnetic centre(s) of the nearest quadrupole(s)*. Some systematics are intrinsic in the method, due to the physical separation between BPMs and quadrupoles. In addition the number of quadrupoles (248) in the SR exceeds the number of BPMs (172) such that a one to one correspondence is not always possible, as illustrated in Table 2. Every ordinary cell contains 10 quadrupoles and 7 BPMs. BPM_1 and BPM_7 are named *primaries*, being used to define the trajectory in the straights between the double bend achromats, while the other BPMs are *secondaries*. Primary BPMs are mounted on the SR floor, while secondaries are mounted on the magnet girders.

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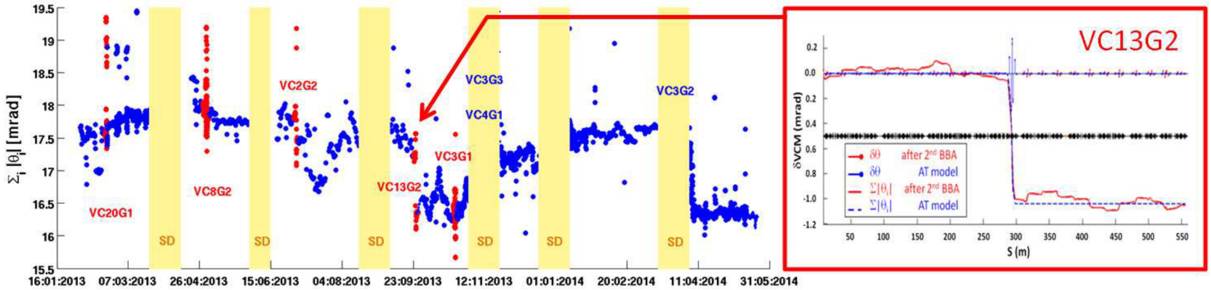

Figure 1: Vertical re-alignment moves over a year. Dots are the integrated corrector strength in the machine. Red dots refer to girder moves during machine development sessions. The inset highlights VC13G2 case, with a clear benefit due to the enhanced alignment in the cell. In some cases, like VC3G2, moves happened during SD periods (yellow bands).

Table 2: BPMs and quadrupoles in a typical Diamond three-girder cell, and their association to nearby quadrupoles during BBA runs.

girder#	BPM#	BPM type	Quadrupole#
	1	P	Q1
1	2	S	Q2 Q3
	3	S	Q4
2	4	S	Q5 Q6
	5	S	Q7
3	6	S	Q8 Q9
	7	P	Q10

SURVEY DRIVEN RE-ALIGNMENT

Global surveys of the horizontal and vertical positions of the girders in the SR are taken regularly, generally during shut down (SD) periods. Local surveys can be requested, typically when a move is executed. Such measurements constitute our prime source of information about the position of the magnets around the SR. Survey Data are injected in the AT model of the machine where five moves have been implemented so far:

- shift in the horizontal plane (sway)
- angular tilt in the horizontal plane (yaw)
- shift in the vertical plane (heave)
- angular tilt in the vertical plane (pitch)
- angular tilt around the s-axis of the girder (roll)

Information on the relative position of the magnets w.r.t. the girder median axis has also been introduced. Especially in the vertical plane we still observe a discrepancy between the natural orbit measured in the machine and the one generated in the misaligned model [2]. However an extensive campaign of measurements has proven that as long as we control the imparted move on a girder, then we can predict the effect on the correctors (and hence the distortion of the orbit) in a very accurate way.

STRATEGY AND TESTS FOR A TRANSPARENT RE-ALIGNMENT

A girder move is achieved by powering up 5 different cam motors, each for the 5 axes involved in the action. At present moves are imparted by means of a portable rack controlling these 5 stages, and require access in the SR tunnel on dedicated sessions during which some Linear Variable Differential Transformers (LVDT) are temporarily mounted, to ensure that any move will be within pre-defined tolerances. During these sessions the survey team is also present to monitor and validate the move. In order to increase our level of predictability few BBA iterations are run before and after the change. It was shown that with such procedure the variation in the correctors can be well reproduced [2]. The sum over corrector strengths $\mathcal{S} = \sum_{i=1}^{172} |\theta_i|$ is another parameter used to confirm the validity of a move. If the cell is brought to a state of improved alignment, a reduction in the overall corrector strength is expected, with a clear signature at the cell where the move took place, as shown in inset of Fig. 1 for the vertical re-alignment of girder 2 in cell 13 (VC13G2). Fig. 1 shows the evolution of $\mathcal{S}$ as a function of time, for year 2013, where eight girders were moved vertically.

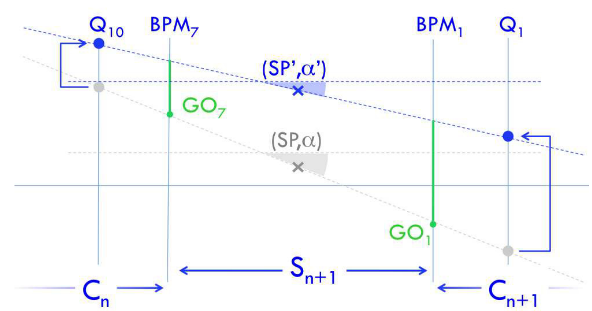

Figure 2: Concept of transparent re-alignment.

One of the potential problems when executing a global re-alignment of the machine, is the impact on the beamlines facing cells undergoing the move: we define as *transparent* a re-alignment (TR) that minimizes its effect on all beamlines. The illustration of the case and the proposed solution

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is shown on Fig. 2. The move involving cells C_n and C_{n+1} entails a displacement of quadrupoles C_nQ_{10} and $C_{n+1}Q_1$ and the consequent re-definition of the orbit in the straight S_{n+1} (dashed blue line) that can be characterized by a new Source Point and a new slope (SP′,α'). The orbit can be restored to its pristine configuration (SP,α) by introducing offsets in the primary BPMs facing the straight. These Golden Offsets (GO) partly destroy the beneficial effect of a BBA, however they offer more flexibility, since an initial alignment issue is translated into an easily controllable parameter. A GO can be re-defined and even zeroed, should the beamline re-align to the machine.

The case of VC3G1

The first test of the validity of the method involved the vertical move of girder 1 in cell 3 (VC3G1). A heave of -245 μm and a pitch of -21 μrad were imparted so to place the first girder of the cell at zero height. This move increased the dipping angle at the straight, requiring a compensation via a GO at the first primary BPM of cell 3 in order to minimize the impact on beamline I03. Fig. 3 summarizes the

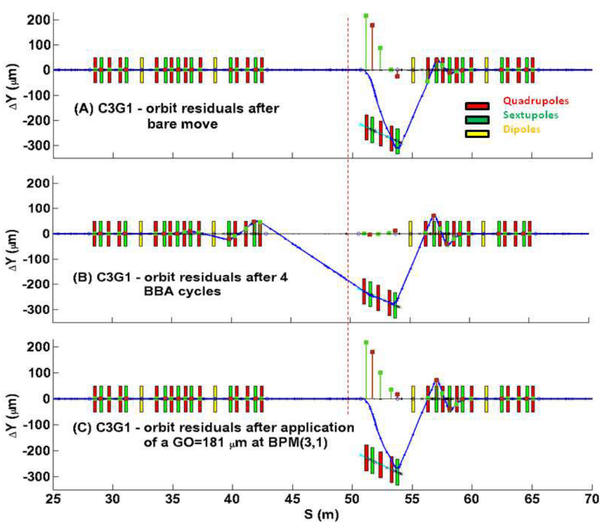

Figure 3: Predicted orbit residuals after the VC3G1 move. (A) bare move, (B) after 4 BBAs, (C) after application of a 181 μm GO at BPM(3,1) (vertical red line). Stems show the residuals at quadrupoles (green) and sextupoles (brown).

effect of the move and the subsequent corrections on the beam orbit. In particular it can be observed how a series of BBA measurements brings the orbit to the centres of the quadrupoles, while the final applied GO partly spoils the beneficial effect of the BBA. Albeit not ideal, this solution is the only possible to make the move transparent to I03. While a GO=181 μm brings the orbit in straight 3 as it was prior to the move, it was found that GO=161 μm was sufficient to make the change at I03 unnoticeable. Given the importance of the BBA procedure we compared measured and predicted BBA offsets for a four cycle measurement in cell 3, finding a remarkable agreement, as shown in Fig. 4 (A). It can be appreciated the importance of executing several BBA cycles, until offset variations are of the order of few μm: stopping the BBA process too early would lead to higher orbit residuals than the ones seen in Fig. 3 (B) and

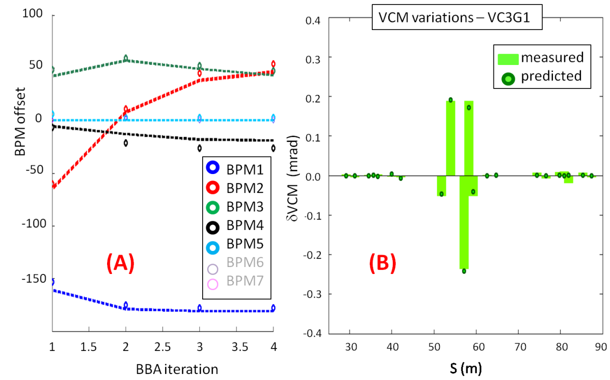

Figure 4: (A) BBA measurements for VC3G1 move (dots) as compared to AT predictions (dashed lines).(B) Comparison between measured (bars) and computed variations (dots) of the VCMs at cell 3 after four BBA iterations.

the comparison of corrector variations would not match as nicely as shown in Fig. 4 (B).

CONCLUSIONS AND FUTURE WORK

The successful campaign of tests culminated with the first transparent re-alignment at straight 3 made us confident in proposing a TR project, that has been recently approved. The next stage consists in equipping three chosen cells with permanent LVDTs, so to protect the motion of girders from undesired excessive shifts, and in commissioning these cells for the move. This will be accomplished during SD periods. After the commissioning a cell will be deemed safe to be moved from the Diamond control room, easing and shortening the phase of measurement and validation with the involved beamline. The re-alignment moves and measurements will take place during machine development sessions. Given the present SD schedule, the TR project aims at re-aligning three cells between now and the beginning of next year. Pending the good results of these moves, we expect to extend the procedure to other parts of the machine.

ACKNOWLEDGEMENTS

We wish to thank the Survey Team for their invaluable help during tests and K. Mc Auley from I03 beamline for her cooperation and help in our first TR test.

REFERENCES

[1] R. Dowd *et al.*, "Achievement of Ultralow Emittance Coupling in the Australian Synchrotron Storage Ring", PRST-AB 14, 012804 (2011).

[2] M. Apollonio *et al.*, "Girder Alignment in the Diamond Storage Ring", Proceedings of IPAC2013, Shanghai, WEPME054, p. 3052 (2013).

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