

LONG-TERM STABILITY OF THE DIAMOND LIGHT SOURCE STORAGE RING

M. Apollonio, K. Baker, W. J. Hoffman, J. Kay, V. Kempson, I. Martin,
Diamond Light Source, Oxfordshire, U.K.

R. Bartolini, Diamond Light Source, Oxfordshire, U.K. and John Adams Institute, Oxford, U.K.

Abstract

The Diamond Storage Ring (SR) has been in operation since January 2007. This paper summarises a number of measurements that have been made over that period to monitor the SR stability in height and position including general survey, Hydrostatic Levelling System (HLS), horizontal and vertical magnet corrector strengths as well as Radio Frequency (RF) measurements that have given an indication of changing circumference.

INTRODUCTION

Diamond is a 3rd generation synchrotron light source that has been operating since 2007. At present 20 out of 22 available straights are in use for Insertion Device (ID) beamlines and 5 Bending Magnet (BM) beamlines are running, with provision for new beamlines in the next years. The Storage Ring (SR) operates at a vertical emittance of 8 pm rad (coupling=0.3%), whose value is kept stable by means of a feedback system [1]. The machine usually runs in top-up mode, at a typical current of 300 mA, with different injection patterns. The typical lifetime is presently 16 hr. The Storage Ring (SR) underwent an important change in 2011, when straight 9 and straight 13 were modified to allow the insertion of two mini-beta sections.

With such a complex environment it is important to verify the mechanical stability of the system. This is accomplished both by means of dedicated systems (e.g. survey devices) and by use of devices typically employed for other primary goals (e.g. Beam Position Monitors for the control of the orbit).

SURVEY AND GENERAL ALIGNMENT OF THE STORAGE RING

As described in [2], mechanical misalignment of magnets in the SR is the main cause of orbit distortions. 172 Corrector Magnets (CM) are used to compensate for this effect, by steering the beam to the zero of 172 Beam Position Monitors (BPM) where the orbit is sampled. While orbit corrections ensure that the beam is passing through the zero of the BPMs, non-zero orbit and dispersion between the BPMs can generate spurious multipoles, whose net effect is typically an increase in vertical emittance and a reduction in dynamic aperture. It should also be stressed that excessive orbit distortions might not be correctable, due to excessive demand of steering power on the correctors. These considerations suggest that a general survey of the machine can give important information on the present status of the lattice.

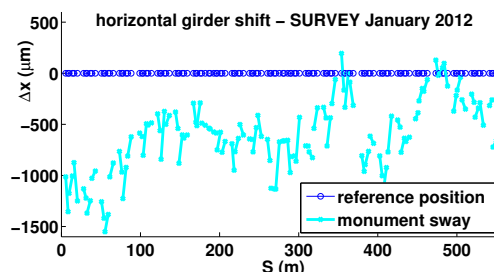


Figure 1: Horizontal shifts of girder monuments as recorded in January 2012 survey (cyan segments). Almost all the girders lay within the circumference of the reference monument positions (blue segments). This suggests a shrinking effect (see text).

Surveying of the 561.6 m long SR is accomplished by a network of 48 instrument stations and 96 wall nests distributed in the SR tunnel. A total of 148 monuments mounted at the edges of the 74 girders hosting all the lattice magnets, is used to define the planimetric and vertical positions of the girders. In the planimetric view a χ^2 fit to a reference set of data taken on August 2006 is used to define the current location of all the monuments. In the vertical view a best fit plane is found which interpolates all the monuments. In such way we are left with relative modulations with respect to a baseline, which is the relevant information for what concerns the effect of misalignments on the machine. Precision of survey measurements on each monument varies, with values typically in the range of 50 to 100 μm [3].

Horizontal Plane Misalignments

Analysis of survey data shows that significant displacements are present in the machine. Fig. 1 is a graphical representation of a horizontal survey taken in January 2012 where monuments at the edge of a girder are shown as a function of the longitudinal coordinate along the ring. The cyan segments join pairs of monuments that belong to the same girder. Side displacements (sways) larger than 1 mm are visible, with an average sway of $-615 \mu\text{m}$, pointing towards the centre of the SR and suggesting an effect of shrinking of the machine. In order to better understand this effect we have analysed a set of data taken in 2013 from a measurement of girder roll angles. The result shows that magnet centres sways due to rolls are of the order of $30 \mu\text{m}$, far smaller than the aforementioned shrinking which we believe being due to a genuine effect. Another hint suggesting a circumference shrinking is represented by the increasing trend in

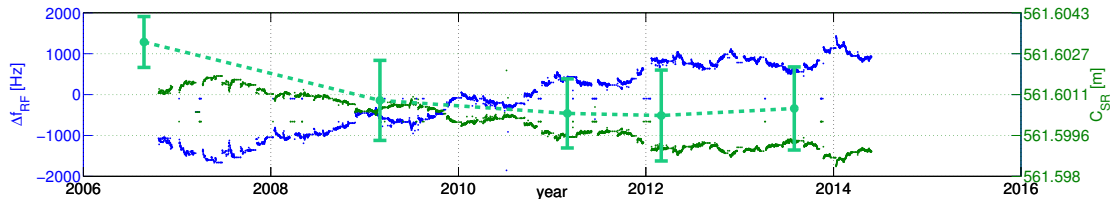


Figure 2: (Blue) recorded values for RF frequency in the Diamond SR ring over seven years. A clear increasing trend is seen with a seasonal modulation. (Green) extrapolated ring circumference (see text) showing a change of about -1.9 mm in path between October 2006 and August 2013. Green bars show the measured values from survey data with error inferred from the precision on monument position.

Table 1: Storage Ring path length. Comparison between survey data and inferred path from recorded RF values (see text for details). Reported variations refer to the C_{SR} in bold characters.

date	survey (mm)		RF inferred (mm)	
	C_{SR}	ΔC_{SR}	C_{SR}	ΔC_{SR}
08/2006	561603.17			
10/2006			561601.20	
03/2009	561600.92	-2.2	561600.60	-0.6
03/2011	561600.42	-2.7	561599.52	-1.7
01/2012	561600.36	-2.8	561599.11	-2.1
08/2013	561600.61	-2.6	561599.31	-1.9

the RF frequency used in the SR to keep the electron energy constant at 3.0 GeV. Fig. 2 shows an archive snapshot of the RF frequencies (blue dots) for a period of about seven years, dating back to October 2006. The graph can be translated into a change in SR path (green dots), via the formula

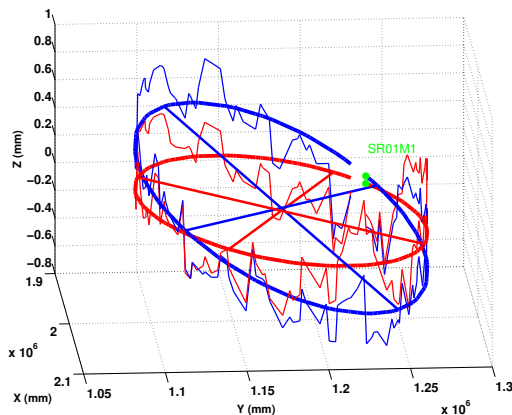


Figure 3: Best fit planes for two vertical surveys, January 2013 (blue) and August 2013 (red). A general tilt is clearly visible (thick line circles). The thin lines join the actual surveyed positions of the girder monuments.

$C_{SR} = ch/\nu_{RF}$, where the SR circumference is expressed as a function of the speed of light, the harmonic number (936) and the RF frequency. A variation in circumference of about -1.9 mm can then be estimated between October 2006

and August 2013. Another way to calculate C_{SR} is by using the sum of the inter-distances between monuments. The systematic excess of about 6.4 cm in path due to the positioning of the monuments on the dipoles is subtracted and the instrumental precision on each surveyed monument is propagated to calculate an error on C_{SR} . Results are shown on Fig. 2 and reported on Table 1. A similar decreasing trend observed in the C_{SR} from survey measurements confirms the result inferred from the RF, albeit the large error bars make the former a less compelling evidence for the shrinking of the circumference.

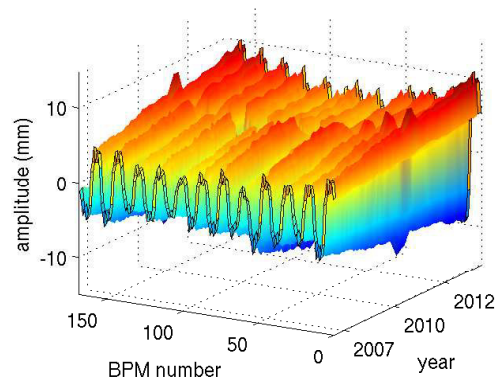


Figure 4: Vertical Natural Orbit evolution in time (2007-2013).

Vertical Plane Misalignments

Survey measurements provide an estimate of the vertical variations for the girder monuments w.r.t. a best fit plane interpolating all the measured points. Fig. 3 shows variations of the best fit planes from two different surveys. Table 2 reports a summary of girder vertical misalignments in the machine. Misalignments in the vertical plane require spe-

Table 2: Summary of Diamond SR girder vertical positions and tilt angles according to January 2013 survey.

V-plane	mean	σ_V	MAX
heave (μm)	-1.9	201.6	514.7
pitch (μrad)	-11.7	40.0	170.0

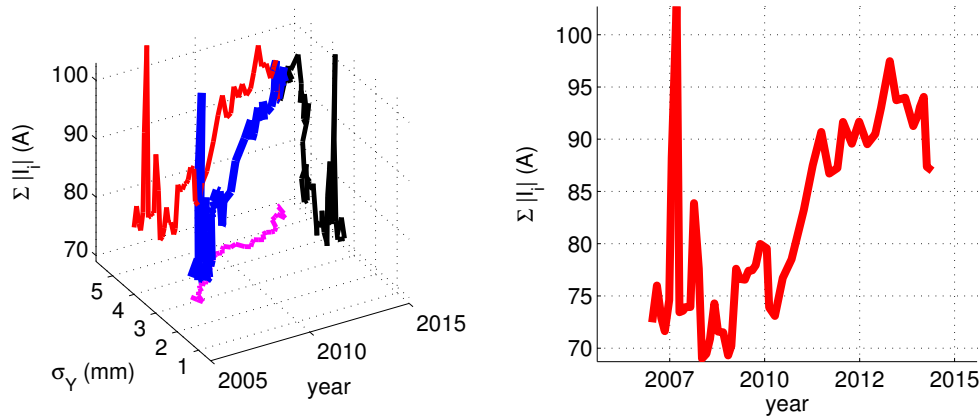


Figure 5: (Left) Blue curve: Total corrector strength versus orbit size versus time (years 2007-2013) and its projections: (red) total CM strength versus time, (purple) orbit size versus time, (black) total CM strength versus orbit size. (Right) detail from the left plot, showing the total corrector strength as a function of time.

cial attention, since large girder displacements translate into high CM values, with potentially large orbit distortions. As discussed above, this conspires against a good control of the 8 pm rad vertical emittance and should be kept under control. Monitoring the equilibrium orbit is a possibility, as illustrated in the next paragraph. Re-alignment of the vertical plane is under way, as reported in [2].

NATURAL ORBIT EVOLUTION

Fig. 4 illustrates the evolution in time of the natural closed orbit for the vertical plane, as obtained from the corrector pattern. The bump observed around year 2011, corresponds to the new mini-beta optics, when the vertical tune varied in several steps (from 12.363 to 13.371), and was close to an integer resonance for some time. However the striking feature of Fig. 4 is the monotonic increase in the orbit envelope. This effect is accompanied by an increased demand for corrector strength, as seen in Fig. 5 (left) where the total CM strength ($\sum_{i=1}^{172} |\theta_i|$), the natural orbit size (σ_y) and the time are all positively correlated variables. Fig. 5 (right) focuses on the total CM strength as a function of time, revealing how during 2013 the girder moves for vertical re-alignment produced a net reduction in the overall kicking angle from the steerers [2].

HYDROSTATIC LEVELLING SYSTEM

A Hydrostatic Levelling System (HLS) is operating since 2008. In its new fashion dating back to 2012, it consists of 12 pot sensors distributed along the SR, one for each even cell. Analysis of HLS data complements the survey results. The January 2013 vertical survey shown in Fig. 3 (blue set) identifies two antipodal regions around the lowest and highest point in the best fit plane. The closest even cells to these points are SR08 and SR20. Fig 6 displays the difference in measured levels of the two corresponding HLS pot sensors, revealing a modulation in time. This difference is related to

the inclination of the concrete slab where the SR sits, however it refers to some initial configuration when the HLS was set up. We can however consider the two moments in time corresponding to January 2013 and August 2013 surveys: the variation between the two points is 760 μm which matches within few μm with the best fit plane variation recorded at the aforementioned vertical surveys for the same antipodal points.

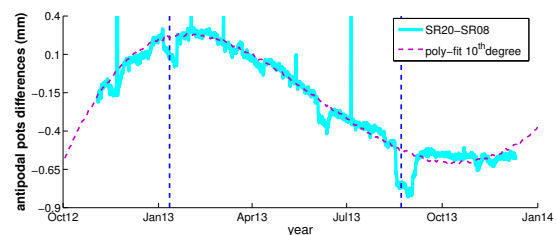


Figure 6: Difference in levels as recorded by the HLS pot sensors at SR08 and SR20 (cyan curve). These cells are the closest ones to the lowest and highest point of the best fit plane from January 2013 vertical survey. A polynomial fit (purple line) is used to infer the level difference at January and August 2013 surveys (vertical dashed line).

CONCLUSIONS

We have shown different techniques employed at Diamond to monitor the mechanical stability in the SR. Correlation between different methods has been highlighted. All these activities will complement the project of vertical re-alignment of the machine [2].

REFERENCES

- [1] I.P.S. Martin et al., Proceedings of IPAC2013, MOPEA071, p. 249 (2013).
- [2] M. Apollonio et al., Proceedings of IPAC2014, MOPRO101.
- [3] W. Hoffman, private communication.