DOUBLE MINI-BETA-Y PLUS VIRTUAL FOCUSSING OPTICS FOR DIAMOND STORAGE RING

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Abstract

A proposal has been developed to modify a long insertion straight (~11.4 m long) of the DIAMOND storage ring. Additional quadrupoles provide two sections with small vertical β-function values, in order to accommodate two canted in-vacuum undulators for the imaging and coherence branches of the I13 beam line. A further requirement was to provide a horizontal focusing of the emitted undulator radiation by means of a positive α_x in the second section. This optics is obtained using a small relaxation of the "π–trick" condition, approximately preserving the on-momentum nonlinear dynamics of the ring. The effects of the optics on beam dynamics (i.e. beam lifetime, injection etc.) and possible compensation schemes are presented.

INTRODUCTION

The Diamond storage ring was commissioned in 2006 [1]. It is presently operating at the design tune point (Q_x=27.22, Q_y =12.36) of a low emittance lattice with top-up at 250 mA. The ring has six long (~11.4m) straight sections in addition to eighteen short insertion straights. The long straight sections have a high vertical beta function of 5.8m at middle.

For the beamline I13 at Diamond, two independent branches are planned, one for coherence the other for imaging applications. The operation energies are 6-20 and 8-30keV respectively, where for the coherence branch an undulator with a large number of periods should ensure a high brilliance. This means that the undulator should be as long as possible and that the period length should be short. The undulators for the two different branches are canted for independent operation of the branches.

The present optics in the long straight sections is not suitable for installation of narrow gap insertion devices (IDs) and mini gap in-vacuum undulators. In order to utilize the long straight to accommodate the requirements of the imaging and coherence I13 beamline, two modified optics were studied: a two mini β_y optics [2] and virtual focussing optics [3]. Eventually, it was decided to combine both optics in one having a virtual focussing in horizontal plane and two mini β_y sections. It is achieved by a setting a large β_x and a positive α_x at centre of an ID. The horizontal photon beam size and divergence are calculated from the convolution of the electron beam and single electron photon emission contributions according to:

$$\sigma_{xp} = \sqrt{\varepsilon_x \beta_x + D_x^2 \delta^2 + s^2 \frac{\lambda}{2L}}$$

$$\sigma'_{xp} = \sqrt{\varepsilon_x \gamma_x + D_x'^2 \delta^2 + \frac{\lambda}{2L}}$$

where s is the distance between the source and some point downstream in the beamline front-end, $\beta_x(s) = \beta_{x0} - 2\alpha_{x0}\, s + \gamma_{x0}\, s^2$, $D_x(s) = D_{x0} + D'_{x0}\, s$, $D'_x(s)=D'_{x0}$, the suffix 0 represents the value at centre of an ID, D_x is dispersion, 2L is length of undulator and λ is the wavelength of the radiation. The minimum of horizontal β function at the position s is achieved for $\alpha_{x0}=\beta_{x0}/s$ and is given by β_x=s/α_{x0}. The modification to the linear optics of our long straight sections allowed us to reach $\beta_x \sim 25$m and α_x =1 at centre of downstream ID. The comparison of virtual β_x between two mini β_y plus virtual focussing and two mini β_y optics is shown in Fig.1.

The new optic implementation has serious hardware implications which require redesign of upstream (G1) and downstream (G3) girders as well as vacuum vessel. The strength of the first existing quadrupole (Q1D) required for this optic is above the capabilities of the present power supplies and requires a hardware upgrade. In addition, four new quadrupoles are needed which are among the type used in the ring.

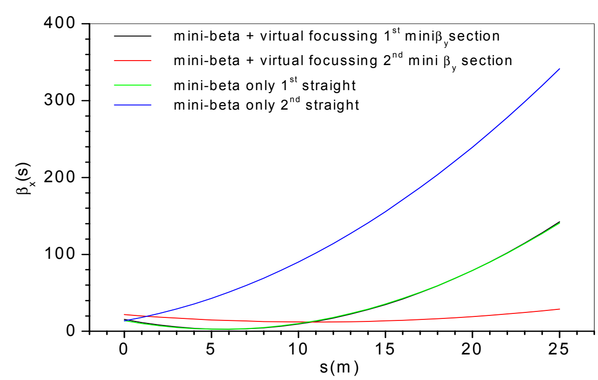

Figure 1: comparison of the virtual β_x downstream beamline between 'two mini β_y + virtual focussing' and 'two mini β_y' optics

ADVANTAGES FOR I13 BEAMLINE

The implementation of the two mini β_y plus the virtual focussing optic provides several advantages compared to the unmodified layout of the straight. First, the modification has a strong impact on the undulator performance. A comparison with/without new optic can be found in Fig.2. Since a smaller undulator gap of down to 5mm is achievable the brilliance differs by more than one order of magnitude and even more at higher energies. Also the undulators can be placed in the ideal positions in sub-sections for best performance. Finally there is another interesting feature is virtual focussing which allows to have fully coherent beam without loosing flux for coherence related experiments.

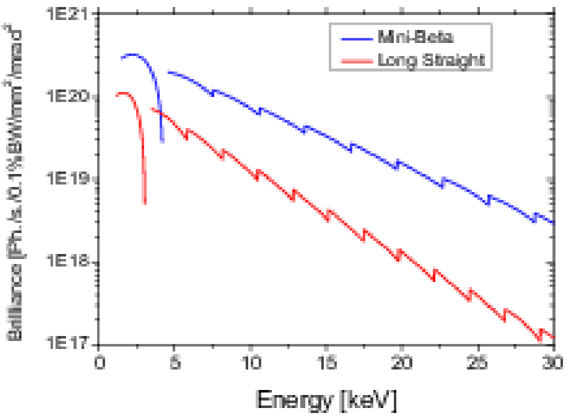

Figure 2: Comparison of a 3m long U20 cryo-cooled undulator (blue) in a mini-beta section and a comparable undulator in a long straight (U28).

OPTIC DESIGN AND OPTIMIZATION

We redesigned the optics of the long straight section with the following goals:

- retain existing quadrupoles so that machine can be run without modification if needed.
- keep other beamlines unaffected by keeping beta functions unchanged.
- keep minimal effect on injection efficiency and Touschek lifetime due to top-up.

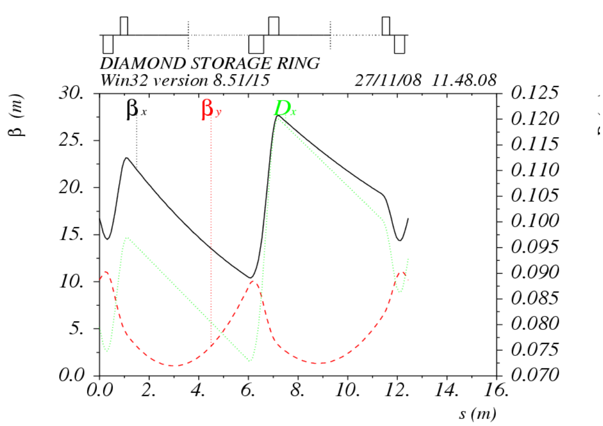

Figure 3: Optics functions in modified long insertion straight.

The solution for the linear optics has been found and optimized treating the straight section as a transfer line starting at the last quadrupole of the arc and ending with same quadrupole. Only two of the existing quadrupoles (Q1D) were used in the matching: these have no sextupoles in between them and allow the use of the π–trick [4] to keep the on-momentum nonlinear dynamics unperturbed. To obtain two mini β_y sections as well as large β_x and α_x ~1 at the centre of second ID in the straight section, we were forced to allow small deviation from the theoretical condition defined by the π–trick. Four extra quadrupoles with doublet at middle of the straight have been used. The optical functions of modified straight are shown in Fig.3. The optimized solution accommodates in the upstream part of the straight section an ID with 2m length and 5mm gap while the downstream part of the straight section can accommodate a 2.8m long ID with 6.1mm gap of downstream ID. The new tunes of the machine, after compensating small deviations using all ring quadrupoles, are (27.22, 12.86). The emittance can be kept to the unperturbed value of 2.75nm.

NONLINEAR DYNAMICS

To investigate the effect of this modification on the ring dynamics, dynamic aperture (DA) and Frequency Maps (FM) were computed using TRACY II [5]. After correcting the chromaticity to zero a small reduction of the DA was observed. Fig. 4a reports the on-momentum DA with 1% coupling: the reduction is few millimeter in x and y but still sufficient for injection. The corresponding x-dp/p DA is shown in Fig. 4b. The x-dp/p DA reduces to zero for dp/p ≈ -4%: this is caused by the fact that Q_y approaches the integer resonance (see Fig.4c) which reduces the negative momentum acceptance of ring and has an impact on the Touschek lifetime as well as injection efficiency.

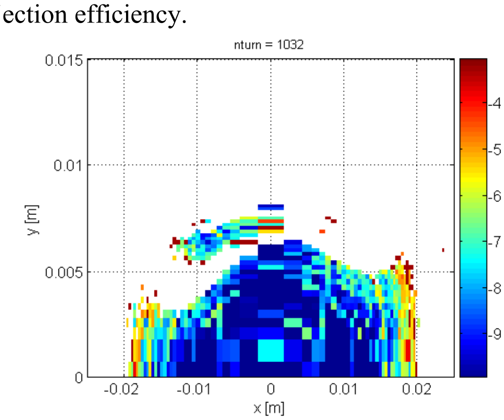

Figure 4a: DA computed with I13 modification with 1% coupling generated by roll off quadrupoles.

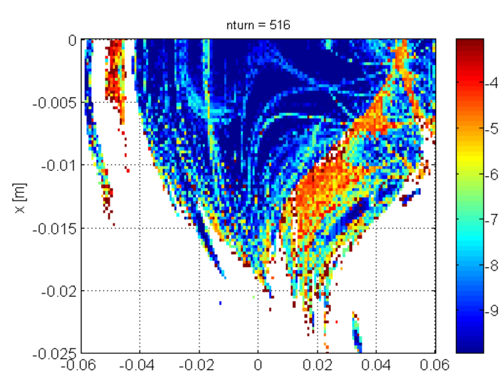

Figure 4b: x-dp/p DA for 1% coupling

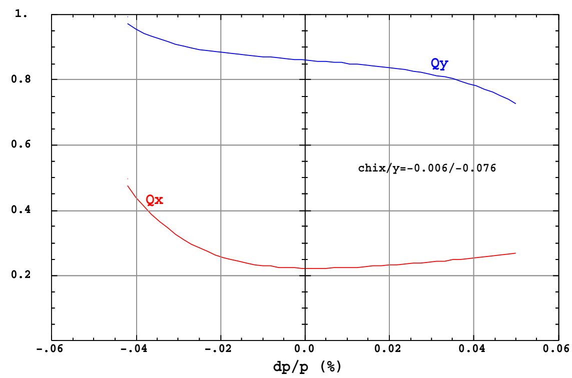

Figure 4c: Fractional tunes with dp/p (%).

INJECTION EFFICIENCY

In view of the high injection efficiency required for Top-Up operation we have carefully investigated the effect of the lattice modifications on the injection efficiency. A computation method was developed to study injection efficiency using TRACY II as discussed in ref. [6] which uses kick map approach for IDs and uses real engineering apertures. These studies have been performed using kick maps of phase 1 IDs [6], I07, both IDs of I13 beamline, multipolar errors of ring magnets whilst realistic engineering apertures of I20 and of the modified straight were used. The numerical simulations show that the effect of the modification is negligible and the injection efficiency is still close to 90%.

TOUSCHEK LIFETIME

The Touschek lifetime of the modified optics has been computed with kick map approach for IDs using TRACY II [6], considering real engineering apertures and multipolar errors of the ring magnets as discussed in previous section. The results are listed in table1.

Table1: computed 6D Touschek lifetime (bunch length σ_l =2.8mm, 500mA,2/3 fill pattern)

Case	Touschek lifetime
all Ids with I13 optic+ tunes corr.	9.8h
all Ids with I13 optic+no tunes corr.	8.9h
bare lattice with I13 optic	10.4h
bare lattice without I13 optic	11.2h

The I13 optic can reduce the lifetime to 9h from 11h if vertical linear tune shift due to IDs is not compensated. This is caused by that fact that Q_y drifts closer to integer resonance. The Touschek lifetime can be recovered partially by correcting Q_y= 0.89 globally to Q_y=0.86 using all quadrupoles of ring, reaching 10h which is deemed to be acceptable.

MODIFICATION FOR I09

There is further plan to repeat the modification of the long straight also for another long straight for I09 beamline. Preliminary feasibility studies have been performed and led to conclusion that new optic can be implemented for both beamlines with marginal effect on injection efficiency and lifetime without need for re-optimization of sextupoles. The DA computed for ring with two modified long straights with this optic and chromaticities corrected with new operating point (27.22, 13.36) is shown in Fig. 5.

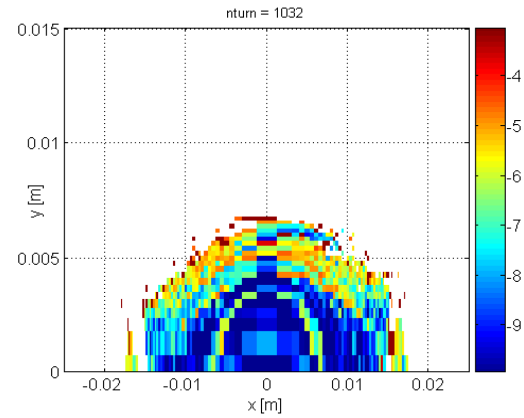

Figure 5: DA with I13 and I09 optic and 1% coupling.

CONCLUSION

The two mini-beta-y plus virtual optic for long insertion straight to accommodate two narrow gap IDs as well as to provide horizontally focussed photon beam from the downstream ID can be adopted for DIAMOND storage without any significant degradation machine performance such as injection efficiency and lifetime.

The injection efficiency is nearly unaffected even in worst case scenario when all multipolar errors of ring magnets and kick maps all IDs including I13 are considered without re-optimization of sextupoles. It is close to 90%. Degradation in lifetime is also not significant. It is still close to 10h which was design specification. Finally, preliminary studies have shown that this optic can be repeated for the stragith section I09 with a new operating tune point (27.22, 13.36). Further investigations are under progress.

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