IMPLEMENTATION OF DOUBLE MINI-BETA OPTICS AT THE DIAMOND LIGHT SOURCE

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Abstract

We report the results of the implementation of two vertical mini-beta and horizontally focussing optics at the Diamond light source, the first in August 2010 and the second in March 2011. Commissioning results of the two optics changes and the experimental characterization of the optics are compared with the expected performance and theoretical modelling. The implications of a possible third customised optics are also investigated.

INTRODUCTION

The Diamond storage ring has six long (~11.4m) straight sections which are not ideal for narrow gap insertion devices due to high vertical beta function (5.8m). To satisfy the Phase-II users' requirements, it was decided to modify two of these straights for I13 and I09 beamlines with double mini β_y and horizontal (virtual) focussing optics. The description of the optics and its predicted effects on operation were discussed in references [1, 2].

I13 is Diamond's longest beamline and has two independent branches dedicated to imaging and coherence experiments. The imaging branch is designed for hard X-ray imaging on the micro- and nano-length scale and required a narrow gap in-vacuum device. The coherence branch additionally required a horizontal focussing optics as well as the experimental station at a long distance of about 250m from the source.

The I09 beamline will have two branches to be used for surface and interface structural analysis. This beamline will combine low energy and high energy beams focused on the same sample area and will achieve advances in structural determination of surfaces and interfaces, as well as in nano-structures and biological systems.

The modified I13 straight section was commissioned in late 2010 and straight section I09 in early 2011. Presently, the ring is operating at working point WP = (27.201, 13.371) with both modified straight sections. The experiences of implementation and commissioning are discussed below.

INITIAL IMPLEMENTATION AND COMMISSIONING OF I13 OPTICS

The requirements on the modified optics for the I13 straight section have been discussed in reference [1]. The assembled I13 straight with downstream undulator (coherence) and middle girder with doublet is shown in Fig. 1. The new optics with design WP = (27.22, 12.86) was quickly established with nearly unaffected injection efficiency.

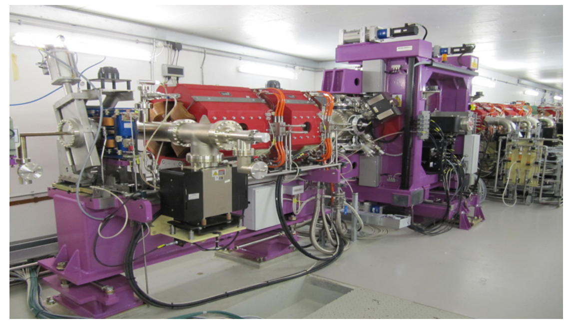

Figure 1: Assembled I13 straight with downstream undulator (coherence) and middle girder with doublet.

Strong beam instabilities were observed when in-vac IDs were closed to a minimum gap of 5mm and could not be suppressed by increasing the chromaticities or using the Transverse Multi-Bunch Feedback sytem (TMBF). At the design stage it was perceived that resistive wall (RW) instabilities could cause a problem for operation due to fact that Q_y is above the half integer [3]. Although the experience at other light sources that implemented similar schemes show that the instability can be controlled with the TMBF, this proved not to be the case at Diamond, possibly due to the large number of in-vac IDs in the storage ring. The evidence of resistive wall instability is shown in Fig. 2 (blue lines) where the typical 1/f decay of the amplitude of oscillations of the mode is shown.

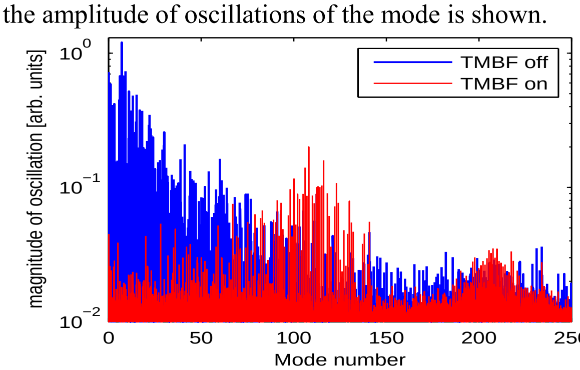

Figure 2: Amplitude of excited modes; blue) without TMBF, red) with TMBF.

NEW I13 OPTICS

In order to achieve a stable, high current operation of the machine, the vertical tune was initially moved by impirical adjustment to Q_y=13.09 to overcome RW instability, which worked well (albeit with reduced lifetime and increased vertical beam motion). A matched optic solution was later found using ELEGANT [4] with WP = (27.23, 13.18) with the constraints that the vertical beta function in all standard straights with IDs and the horizontal beta function in the injection straight are

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unchanged. The optics in the I13 straight is nearly the same. All quadrupoles were used in the matching. The relative deviations of beta functions of the new I13 optics to the old design optics are shown in Fig. 3.

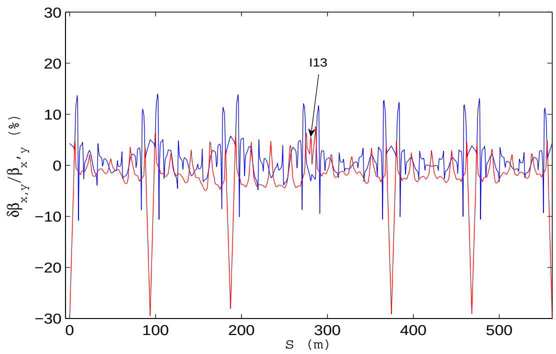

Figure 3: Relative beta beat of new I13 optics w.r.t. old design optics (WP = (27.22, 12.86)).

The emittance of the new lattice is reduced (2.6 nm.rad). This optic worked well with unaffected injection efficiency and good lifetime. The horizontal tune was moved to Q_x=27.23 due to better injection efficiency when all IDs are closed including wigglers. The machine was operated as per schedule in user mode for several months until assembly for modified I09 straight was complete.

I09 OPTICS AND COMMISSIONING

The I09 optics has been obtained keeping the same quadrupole layout as that of I13, but has slightly different horizontal beta functions (see Fig. 4). Feasibility studies [2] showed no perceived difficulty in machine operation with top-up, indicating no effect on injection efficiency and an acceptable reduction of the Touschek lifetime of about 2h.

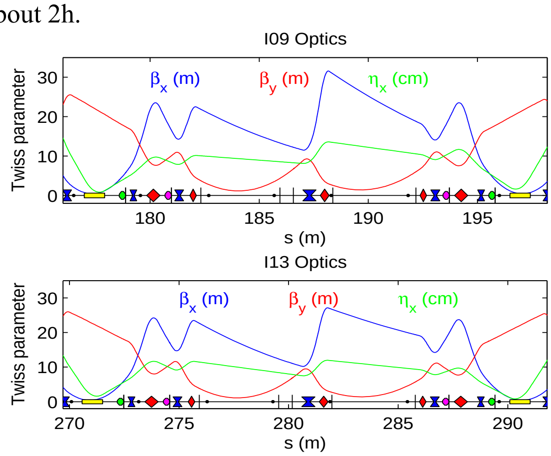

Figure 4: Twiss parameters of I09 and I13 optics in operation.

After the hardware installation, commissioning of the combined I09 and I13 optics began in April 2011. The new optic with design WP = (27.205, 13.36) was quickly established on the first day. In order to further refine the WP, the injection efficiency (Fig. 5) and beam lifetime were measured for different tunes with all IDs closed, SC wigglers on and collimators closed (normal machine operation). This demonstrated that moving the WP (shown by ×) to (27.20, 13.37) improves the lifetime and injection efficiency (~80%), and is far from the skew octupole resonance which has been the problem with some in-vac ID [5]. After commissioning, the machine has been running in user mode at the new WP as per schedule. No sextupole optimisation was required, barring the chromaticity correction.

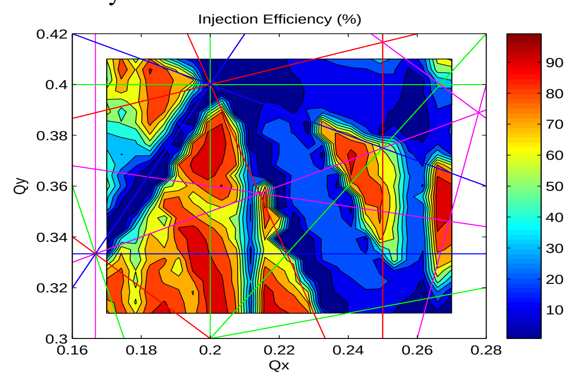

Figure 5: The measured injection efficiency for different tunes with all IDs and collimators closed.

In Fig. 7 the effects of the modifications are assessed using the normalised beam lifetime, starting from before the installation of either mini-beta section. Red markers indicate 900 bunches and green markers are for 686 bunches. The raw data has been normalized to remove the effects of coupling, cavity voltage, fill pattern and bunch current variability. A normalized lifetime of 100% corresponds to the lifetime for 900 bunches, 200mA, 1% coupling and 2.2MV recorded before the installations (run04-10).

Following an initial period of vacuum recovery, a small reduction in normalised lifetime occurred in run 05-10 (the I13 optics was not powered at this stage). In run 06-10 the I13 optics was switched on, and an initial degradation in lifetime observed for 900 bunch operation could be largely corrected by shifting the vertical WP from 13.09 to 13.18. A further reduction occurred following the installation of the I09 hardware, from which the beam lifetime is still recovering. This drop in lifetime is independent of whether the I13 or I09 sections are powered, but is still adequate for user operation.

Frequency Maps measured with and without I09 and I13 are slightly different because of the different WP and chromatic sextupole settings (see Fig. 6).

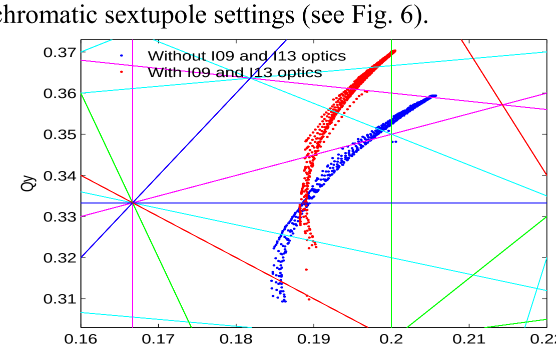

Figure 6: Comparison of measured FM with (red) and without (blue) I09 and I13 optics at ξ_x/ξ_y=2/2.

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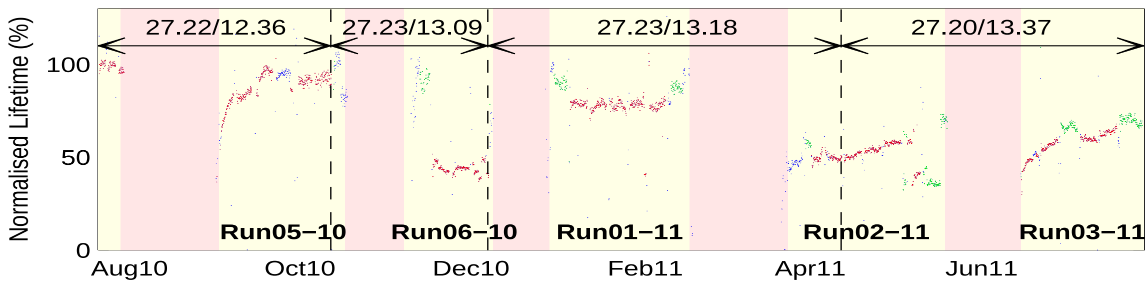

Figure 7: The normalized lifetime during user runs for different optics and fill patterns (900/686 bunches – red/green); Run05-10) unmodified WP= (27.22, 12.36); Run06-10) I13 WP= (27.23, 13.09), Run01-11) I13 WP= (27.23, 13.18), Run-02/-03-11) I09+I13 WP= (27.20, 13.37).

However, there is no indication of excitation of any additional resonances.

The single bunch instability thresholds as a function of the chromaticity (Fig. 8) were measured for the different optics. The possibility of safely operating with high chromaticity of about 2 in both planes is important for running with a hybrid fill pattern. It appears that the new optics has very little effect on instability threshold.

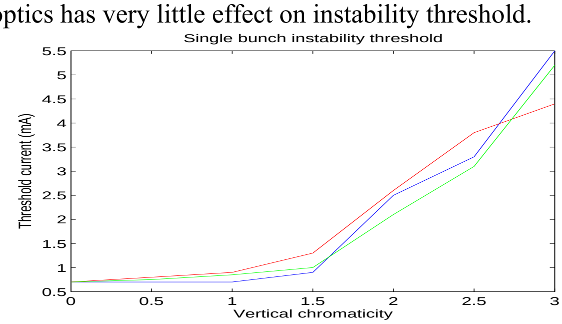

Figure 8: Measured single bunch instability thresholds as a function of chromaticity for I13 (red), I13+I09 (green) and without I09 and I13 (blue) optics.

OPTICS FOR I21 STRAIGHT

I21 is a Phase-III beamline presently under discussion. It envisages one in-vaccum and one APPLE type insertion devices. Two options are being considered: a third double mini β_y plus horizontal focussing optics, or alternatively reducing β_y to 3.4m at the centre of straight using the existing quadropole triplets and keeping tunes fixed. Optical solutions have been found using ELEGANT including I09 and I13 optics and keeping requirements of existing IDs as well as injection and using all quadrupoles as variables. The latter one (Fig. 9)

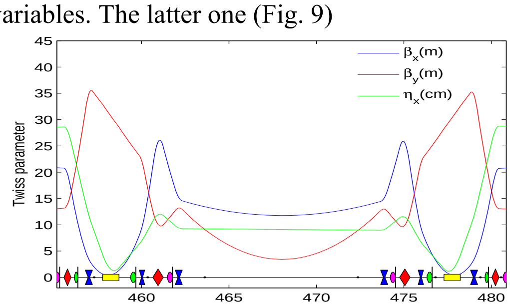

Figure 9: Twiss parameters of I21 optics with β_y=3.4m at the centre of long straight.

was chosen for further investigations because of significant increase in emittance in former case.

The investigation shows no effects on injection efficiency while the Touschek lifetime shrinks by 2h but still has an accceptable lifetime of 10h. The dynamic aperture computed for presently running machine chromaticity of 2/2 is still adequate for injection (Fig. 10).

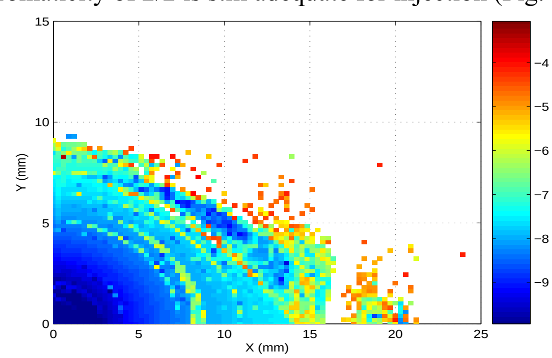

Figure 10: Dynamic Aperture with I09, I13 and I21 optics and WP = (27.205, 13.36).

CONCLUSION

Two of the six long straights of Diamond have been successfully modified and commissioned with double mini β_y and horizontal focussing optics and the machine is running in user mode with top-up without any difficulty. Investigations are being made for another long straight, I21, to lower the vertical beta function to 3.4m keeping tunes fixed. There is no perceived difficulty in operating the machine with this change, along with the already modified I09 and I13 straights.

ACKNOWLEDGEMENTS

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