NON-LINEAR BEAM DYNAMICS STUDIES OF THE DIAMOND STORAGE RING

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Abstract

The non-linear beam dynamics have been investigated for the non-zero dispersion lattice of the Diamond storage ring. Effects in realistic lattice configuration, where coupling errors and engineering aperture limitations are considered, have been studied here. Frequency Map Analysis together with 6D tracking allows identification of the limiting resonances as well as the loss locations and calculation of the influence of non-linear longitudinal motion on the Touschek lifetime. The sensitivity of the lattice to these effects suggests the identification of a better working point for the machine.

1. INTRODUCTION

The Diamond storage ring non-zero dispersion optics at the working point (ν_x, ν_z) = (27.22, 12.36) is characterized by the amplitude and energy tune-dependencies shown in figure 1. The on- and off-momentum beam dynamics have been investigated using Frequency Map Analysis (FMA) [1] together with a full 6D-dimensional tracking, in which coupling errors and realistic vacuum chamber apertures are considered. The TRACY-II code (SOLEIL version) has been upgraded in several ways [2], and now allows an external engineering aperture file to be read using an internal procedure. We have considered the horizontal and vertical apertures of the septum magnet, the tapers, the crotch absorbers and crotch vessels, the fast correctors and primary BPMs and phase 1 ID vessels, and in particular the in-vacuum IDs at their minimum gap (see figure 2). Coupling errors of 1% have been introduced using random rolls on the 240 quadrupoles of the ring. As the fractional part of the off-momentum tune-shift shows a crossing on either side of the energy deviation, we expect a limitation due to the linear coupling resonance ($\nu_x - \nu_z = 15$) [3]. Additionally, there is a fast increase in the fractional tune on the negative side that reaches the ½ integer at around -4%. The tunes could cross several destructive resonances, which FMA helps to identify.

2. ON-MOMENTUM DYNAMICS

The FMA reveals relatively stable particle dynamics until about 5.5 mm and 15 mm in the vertical and horizontal planes respectively (see figure 3). Nevertheless, it shows the excitation of a dangerous node of resonances ($4\nu_x$, $\nu_x + 2\nu_z$, $2\nu_x - 4\nu_z$, $3\nu_x - 2\nu_z$) which can reduce the horizontal stability domain to 10 mm. This is similar to the magnitude of the horizontal oscillations of the injected particles in Diamond ring. To ensure high injection efficiency, it is recommended therefore to avoid this node.

3. 4D AND 6D TOUSCHEK LIFETIMES

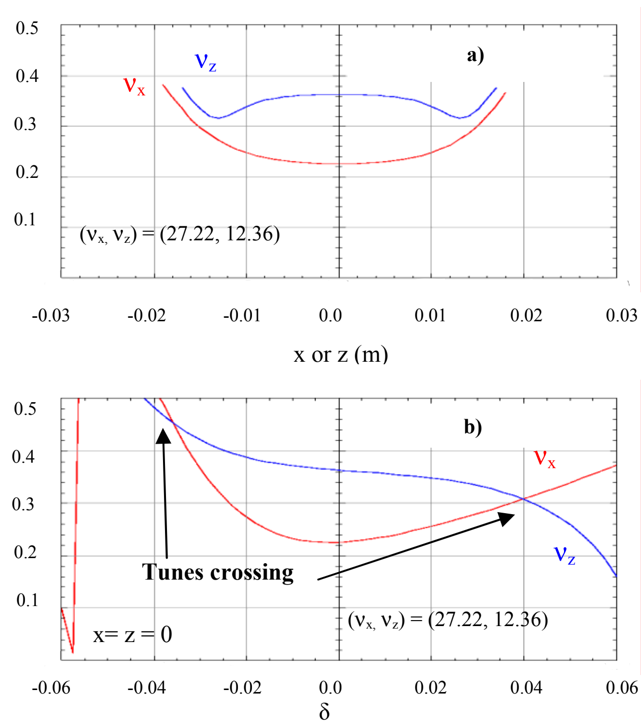

Figure 1: Tune shifts: a) with amplitude, b) with energy for the non-zero dispersion storage ring Diamond lattice.

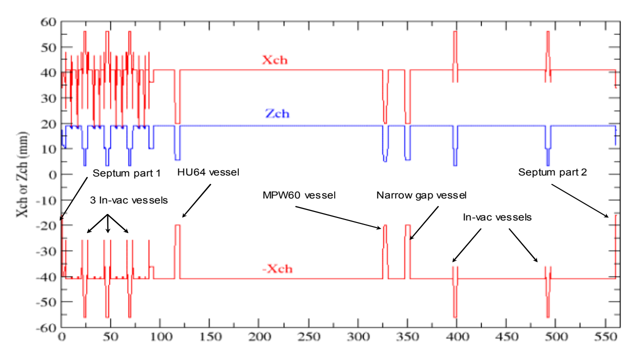

Figure 2: Storage ring engineering apertures considered in the tracking procedure. All the elements are described in the first super period and only phase 1 ID vessels for the rest of the ring.

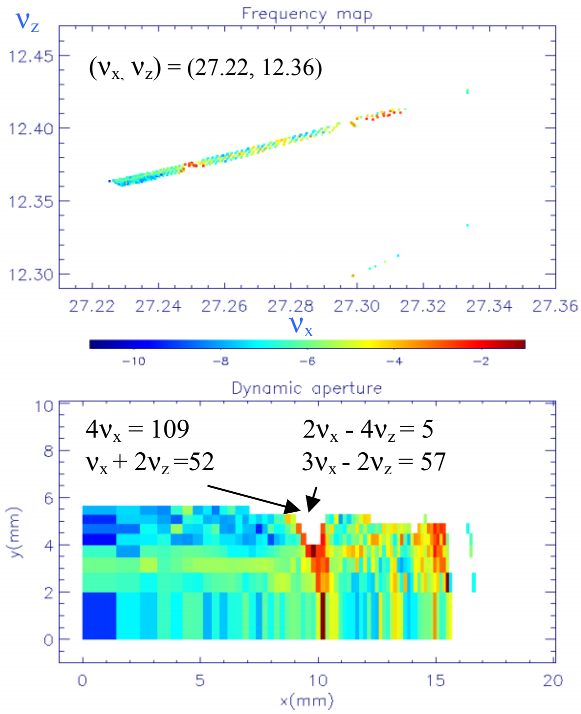

Figure 3: On-momentum frequency map and related dynamic aperture in the presence of 1% coupling errors and vacuum chamber limitations – middle of the injection straight ($\beta_x = 10$ m, $\beta_z = 6$ m).

A small vertical condition (z_0 = 30 µm) has been considered in order to take into account a more realistic model. The momentum deviation is varied from -6% to 6% in steps of 0.1%, and for each step the particle is tracked over 516 turns. The process is repeated at each location of the ring starting at the middle of the long straight (s = 0). For each particle, the loss location and final phase space coordinates are recorded. The RF voltage has been set to 3.3 MV giving an RF acceptance of ± 5% for a bare lattice (without IDs) and a longitudinal stability test is done at ± 6%. The physical aperture has been set according to figure 2. Both 4D and 6D tracking have been performed and the local energy acceptance ε_{acc} is defined as the maximum energy deviation for which a particle with zero initial transverse amplitude remains stable. Figure 4 shows the results of the 6D energy acceptance computations compared to the 4D ones.

In the 4D case, the negative energy acceptance ε^{-}_{acc} can reach - 6% everywhere in the ring, except in the achromat (where the dispersion is highest) where it is limited to around -3.1%. The positive energy acceptance, ε^{+}_{acc}, is limited to + 4% almost everywhere in the ring and can reach +6% in the other locations. Most of the particles are lost in the vertical plane on the in-vacuum undulator vessels (indicated by ''V'' in figure 5). This can happen when some particles cross a region in tune space where their motion is resonantly excited to large vertical amplitudes. We have seen in figure 1 that at around δ = -3% and δ = +4%, particles cross the linear coupling resonance. This has been confirmed by FMA results (see figure 6) where the linear coupling resonance has the most dominant effect on the dynamics. It splits the dynamic aperture completely and contributes to particle diffusion in the vertical plane, so reducing the stability domain on both sides of the energy deviation. An illustration of the loss processes is shown in figure 7. The effect of the linear coupling resonance is clearly identified in 7-a) and seems to have an additional limiting effect to a single or group of resonances in 7-b).

In the 6D case, ε_{acc} is reduced on both sides of the energy deviation compared to the 4D case. ε^{-}_{acc} is now closer to the coupling resonance limit. In the bending magnets (where the dispersion is smallest) the upper limit for ε^{+}_{acc} is now 3.5% and is 2.8% for the rest of the ring. Indeed, due to the high value of the second-order momentum compaction factor ($\alpha_1 = 1.7.10^{-4}$, $\alpha_2 = 1.95.10^{-3}$), a particle with +3.5% energy deviation is below -6% after half a synchrotron period (see figure 8) and is then lost. In addition, a particle with +2.8% energy deviation is below -4% after half a synchrotron period, will experience the coupling resonance limitation and is then lost. In these conditions, the optimistic Touschek lifetime of 19 h obtained in the 4D case is severely reduced to **8h** when a full 6D tracking is considered.

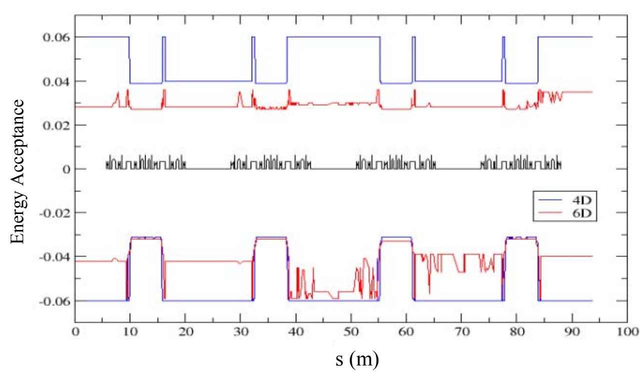

Figure 4: 6D energy acceptance computations compared to the 4D case. The longitudinal bunch length is σ_l = 2.83 mm for a 500mA beam, with 2/3 fill pattern (i.e. 0.8 mA/bunch).

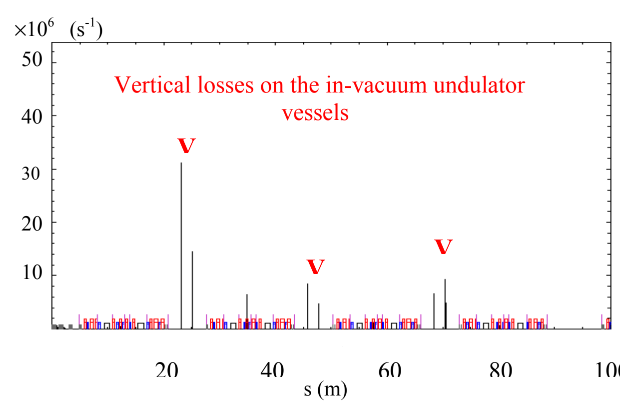

Figure 5: Loss rates as a function of the longitudinal position s, assuming a 500 mA beam and weighting by the probability of having a Touschek event at each starting location in the ring.

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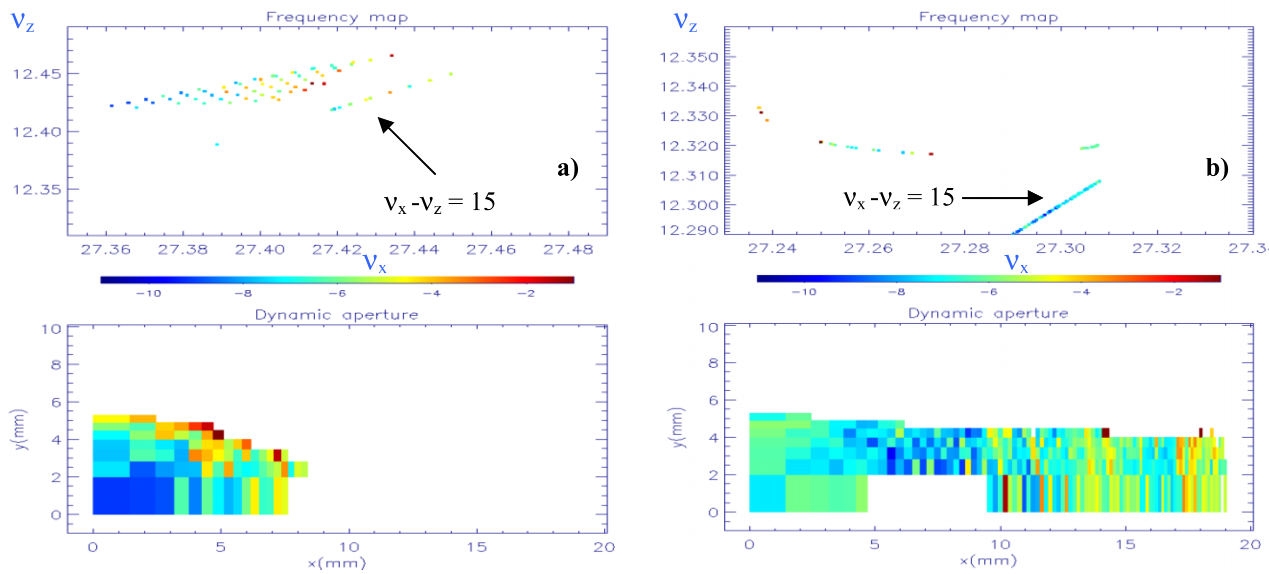

Figure 6: Frequency Maps and related dynamic apertures for: a) δ = -3% and b) δ = + 4% in presence of 1% coupling errors and vacuum chamber limitations – Middle of the injection straight ($\beta_x = 10$ m, $\beta_z = 6$ m, $\eta_x = 7.2$ cm).

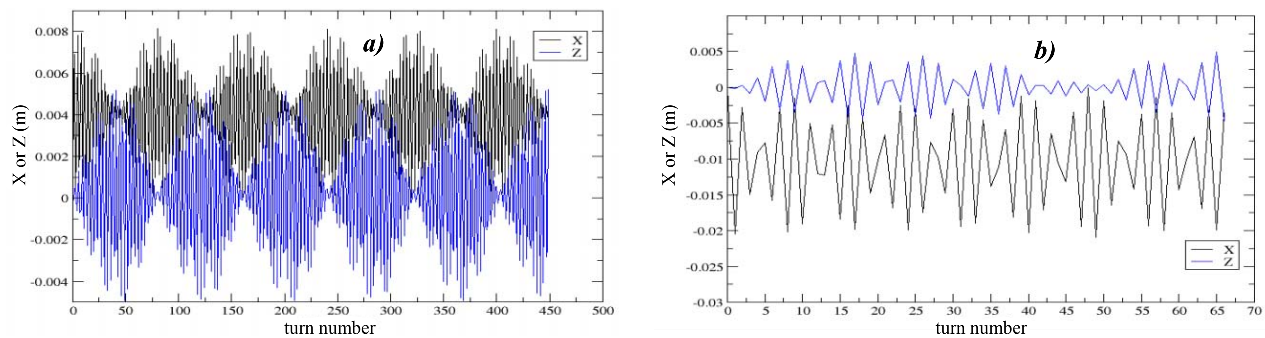

Figure 7: Examples of the loss mechanism limiting: a) ε^{+}_{acc} to + 4 % (tracking at *s* = 4.94 m and vertical loss at s = 25.4 m) and b) ε^{-}_{acc} to -3.1 % (tracking at s = 13.21 m and vertical loss at s = 50.97 m).

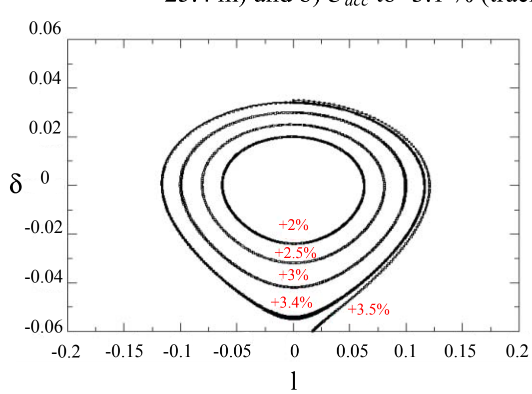

Figure 8: Longitudinal phase space for Diamond lattice.

4. CONCLUSION

The off-momentum dynamics in the Diamond storage ring is highly dominated by the linear coupling resonance, a feature that also has been observed in studies of the SOLEIL lattice [3]. Due to this effect, Touschek-scattered particles are lost on the in-vacuum undulator vessels. This has been clearly identified using Frequency Map Analysis together with a full 6D tracking. The limitations can be more severe when other types of error are taken into account (multipoles, ID*s*, etc) and suggest looking for a better working point. The effect of the second order momentum compaction factor is also significant and contributes about ~50% to the reduction of the Touschek lifetime in the case of Diamond. This effect is a relevant factor for several third generation light sources, such as SOLEIL (α_1 = 4.49.10^{-4}, α_2 = 4.5. 10^{-3}), SLS (α_1 = 6.66.10^{-4}, α_2 = 4.21.10^{-3}) and BESSY II (α_1 = 7.13.10^{-4}, α_2 = 1.58.10^{-3}). It suggests that one should try to take into account the correction of α_2, together with all of the other constraints during the lattice optimization process.

5. REFERENCES

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[2] TRACY II – Diamond version, M. Belgroune et al., report in preparation.

[3] M. Belgroune et al, ''*Refined tracking procedure for the SOLEIL energy acceptance calculation*'', in proceedings of PAC03, Portland, 2003, pp.896 –898.