UPGRADE PLANS FOR THE ESRF STORAGE RING LATTICE

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Abstract

The lattice of the ESRF storage ring is of the Double Bend Achromat type with 32 straight sections of alternating high and low horizontal beta values, currently providing 5 m of available space for insertion devices. As part of the ESRF Upgrade Programme, it is proposed to increase the length of selected insertion device straight sections from 5 to 7 m. In this paper, we will describe the different steps towards longer straight sections: implementation of a new lattice in which the straight section quadrupole triplets are replaced by doublets, design of modified straight sections with replacing the long quadrupoles by shorter ones and moving the adjacent sextupoles, experiments carried out to simulate the breaking of the lattice symmetry induced by a 7 m long straight section.

INTRODUCTION

The ESRF Upgrade Program over the 10 forthcoming years will aim at providing X-ray beams of even higher brilliance and flux, increased capacity for further beamlines and increased insertion device (ID) flexibility. Increasing the length of selected ID straight sections is one of the proposed improvements [1] of the X-ray source.

The ESRF lattice [2] was designed with 2 sets of quadrupole triplets located on both sides of the ID straight sections to provide maximum flexibility and to allow the possibility of setting a wide range of beta values in the centre of the straight sections. This flexibility has never been used and it has been decided to remove one quadrupole on each side of the IDs and to re-arrange the remaining magnets to increase the length available for IDs from 5 to 7 m. As sketched in Figure 1, this upgrade would provide greater brilliance and greater ID flexibility: longer IDs for a single beamline, sharing of a straight section between two experimental stations using the canted undulator approach, reshuffling RF cavities layout and freeing straight section space for new beamlines.

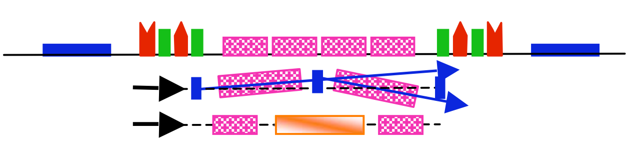

Figure 1: The flexibility of a 7 m long straight section

TOWARDS 7 M LONG STRAIGHT SECTIONS

6 m-long Straight Sections

The first stage of this programme was achieved in 2006 with the implementation in user service mode of a new lattice [3] in which the 2 quadrupoles (QD1-QD8) located on both sides of the IDs were no longer powered. These quadrupoles can be removed, allowing for longer IDs (6 m) to be installed (Figure 2).

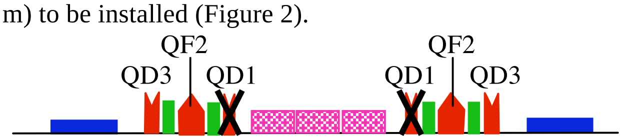

Figure 2 : Layout of a straight section. Bending magnets, quadrupoles and sextupoles are shown in blue, red and green; the 3 segments of an undulator are represented in purple. QD1 (QD8), QF2 (QF7) and QD3 (QD6) are the quadrupoles in a high (low) ß straight section respectively.

7 m long straight sections

The final step in the increase in ID length from 6 to 7 m consists of shortening the long (QF2/QF7) quadrupoles and moving the adjacent sextupole. The quadrupoles and sextupoles located on both sides of the 7 m ID will require a different strength than the other magnets of the same family and will be powered by means of dedicated power supplies. Some of the magnets of the high ß straight sections will require new coils, but in the low ß straight sections the modified QF7 quadrupole would need to have an operating gradient of around 35 T / m. A less challenging solution has been found by balancing the length of the two quadrupoles QD6 and QF7 to obtain similar gradients (25 T / m). Lattice functions are shown in Figure 3. This will involve the manufacturing of two quadrupoles instead of one but thanks to the more conservative gradient, these quadrupoles can be extrapolated from existing designs.

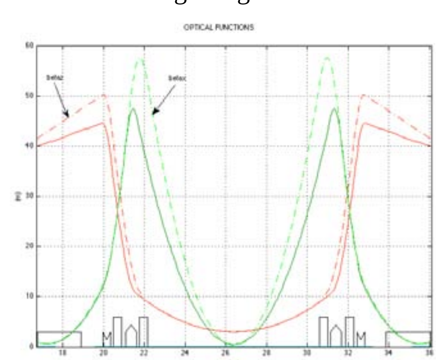

Figure 3: Lattice functions in a 7 m long low ß straight section (plain line) and in a 6 m long one (dotted line).

To minimise costs and shutdowns, the 7 m long straight sections will not be installed on all straight sections but individually on a number of sectors. The drawback of such a strategy is that it breaks the lattice symmetry and may have detrimental consequences on the dynamic aperture, resulting in a drastic reduction in injection efficiency and lifetime.

Simulation of Symmetry Breaking

Obviously the behaviour of a 7 m long straight section cannot be experimentally tested because magnets and coils have not yet been manufactured. On the existing lattice, however, it is possible to detune a straight section and break the periodicity by locally re-powering the QD1 or QD8 quadrupoles and tuning each magnet of the straight section individually. This capability was implemented several years ago on 3 high ß straight sections (ID4, ID6 and ID20) and one low ß (ID11), allowing different combinations of detuned straight sections to be tested. Resonances are excited in a similar way as for a 7 m long straight section, so experimental studies of detuned straight sections provide an efficient tool to assess the feasibility of the 7 m long straight sections. Since the most dangerous resonances excited by the symmetry breaking are odd, they should largely cancel each other out if 7 m long straight sections are installed by pairs 180 ° apart in the ring. Comparing the effects of detuning ID4 and ID20 (at 180 °) or ID6 and ID20 should strengthen or weaken this crucial conclusion for the redistribution of beamlines in the experimental hall.

Tracking simulations show that the dynamic aperture is strongly reduced when detuning one straight section. It can be partially restored by tuning the 2 sextupole families in the detuned straight section, as shown in Figure 4 for a detuned high ß straight section (S4 and S6 are the 2 sextupoles of the straight).

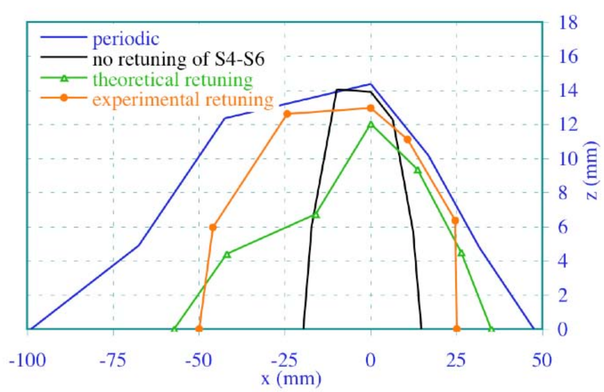

Figure 4: Impact of detuning on the dynamic aperture.

EXPERIMENTAL STUDIES

Lattice with Doublets

Initially the lattice was tuned with $ß_z$ = 3.5 m in the straight sections. The lifetime of this new lattice was significantly smaller than what was achieved with the lattice used from 1996 to 2006. This has drastically improved in 2007 thanks to the increase of the vertical tune by one integer (thus leading to $ß_z$ = 3 m) and the reoptimisation of harmonic sextupoles. The lifetime of the new lattice now surpasses the lifetime of the previous lattice with triplets in all filling patterns, as illustrated in Figure 5. There are very small changes in the electron beam sizes and divergences.

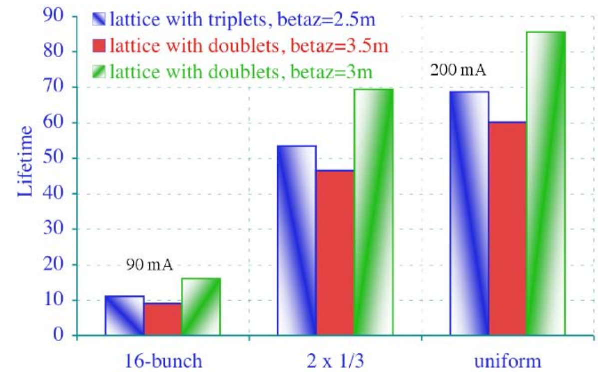

Figure 5: Lifetime comparison.

The non-linear characteristics of the new optics are in good agreement with predictions. This is illustrated in Figure 6, which shows the first experimental map performed using the 8 BPMs recently upgraded with the LIBERA electronics allowing turn-by-turn acquisitions. The tune path is as expected (although there is a slight offset of the zero-amplitude measured tunes as compared to theoretical ones, due to an incorrect tuning). Experimental data remain in the regular region of the map. The fifth-order resonance which had been highlighted in former measurements [4] with the previous lattice is still visible but weaker than before.

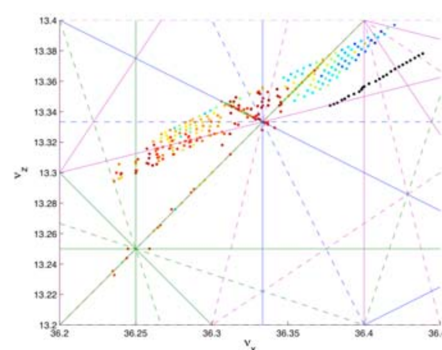

Figure 6: Comparison of experimental frequency map (black dots) and simulations (the colour code of the points indicates the tune diffusion rate on a logarithmic scale).

Detuning of Straight Sections

The procedure for studying the impact of detuning one or several straight sections is the following:

i) First-order tuning: predicted settings are checked via response matrix analysis. A slight retuning of the individual quadrupoles by a few 10^{-4} is usually needed.

ii) Local sextupole tuning: the 2 sextupole families of the straight section are set to simulation values and then scanned to minimise the excitation of the nearest third-order resonances and optimise the lifetime.

iii) Quadrupolar corrections: a set of quadrupolar correctors is computed from the analysis of the response matrix and applied to minimise the ß-beat. The final rms modulation is in the 2-3 % range in both planes.

iv) The H/V coupling correction is performed as for the regular lattice, resulting in a 0.6 % coupling.

v) Sextupolar corrections: the correction of the 2 neighbouring third-order resonances is scanned to maximise the lifetime (Figure 7).

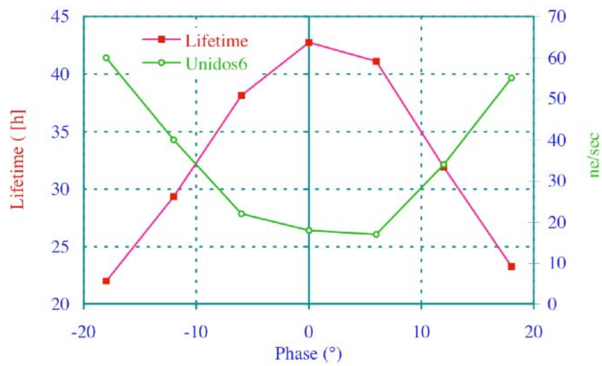

Figure 7: Lifetime and losses evolution during the scan in phase of the correction of the $\upsilon_x+2\upsilon_z=63$ resonance.

Figure 8 shows the lifetime recovery during the tuning procedure of a detuned straight section.

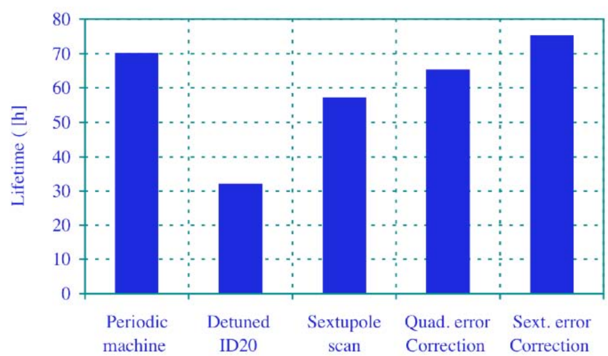

Figure 8: Lifetime evolution during the tuning procedure.

The important figure of merits to characterise the effects of straight section detuning on machine performances is the horizontal aperture, which is strongly correlated to the injection efficiency and the lifetime.

The horizontal aperture is measured by the classical loss rate method: a betatron oscillation of increasing amplitude is generated by one of the injection kickers and the loss rate recorded. The kicker current is calibrated in terms of machine aperture by repeating the measurements when closing the internal jaw of a scraper. As shown in Figure 9, nearly all measurements give an aperture of the order of 15 mm. For a long time, the limitation of the aperture of the periodic machine has been unclear. The new measurements with distorted lattices do not change the landscape: the aperture limitation is an “ESRF constant”.

Since the tests on detuned straight sections were spread over more than one year, different vacuum conditioning stages were met. The direct lifetime comparison for a variable number of straight sections is therefore meaningless and the true figure is the comparison with the lifetime figure of the periodic machine, which was recorded at each different test (Figure 10). No significant lifetime evolution is observed for all tested combinations.

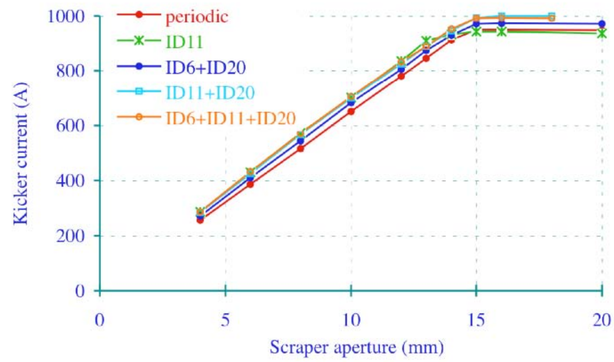

Figure 9: Apertures of the different detuned lattices.

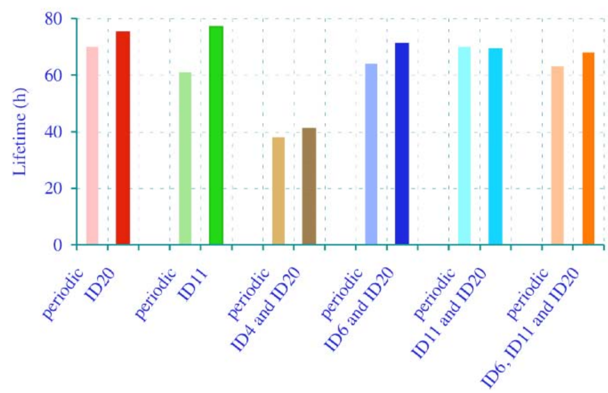

Figure 10: Lifetime@200 mA in 2x1/3 filling for different configurations of detuned straight sections.

CONCLUSIONS

The new optics providing 6 m for IDs has improved performance with respect to the former optics. Thanks to the successful tests with detuned straight sections, the future installation of longer straight sections should have marginal detrimental effects on machine performance.

ACKNOWLEDGMENTS

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