OPTIMISATION OF A NEW LATTICE FOR THE ESRF STORAGE RING

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Abstract

The installation of canted undulators in some of the straight sections of the ESRF storage ring is envisaged in the future. In order to free maximum space in the straight section and minimise the reduction in length of the undulators, a new lattice, in which the straight section quadrupole triplets are replaced by doublets, is being studied. The paper describes the main features of the lattice and presents the experimental results achieved so far.

LATTICE FLEXIBILITY

The ESRF storage ring was commissioned in 1992 with a Double Bend Achromat (DBA) lattice providing a 7 nm horizontal emittance. The structure has a 16-fold periodicity with alternating high and low horizontal betas in the dispersion-free straight sections. Two sets of quadrupole triplets are used in the straight sections to increase the flexibility of the machine.

Since the design stage, this flexibility has been illustrated by numerous changes in the optics:

- In 1995, implementation of a new tuning of the optics with distributed dispersion, enabling a reduction of the horizontal emittance down to 4 nm.
- In 1995, a low alpha version of the optics was tested in view of reaching shorter bunch lengths, at least at low current. A momentum compaction of 1.5 10^{-5} was obtained.
- In 1996, the vertical beta was reduced from 12.8 m to 2.5 m in all straight sections in order to minimise scraping effects induced by the installation of in-vacuum undulators or low gap vacuum vessels.
- In 2000, the horizontal focusing optics providing non-zero alpha function in the middle of one straight section and an increase of flux on the beamline sample was tested.

A NEW OPTICS

To increase the number of independent instruments in some beamlines, it is proposed in the future to split the Insertion Device in a straight section into two shorter IDs generating the radiation at different angles, resulting in a “canted undulator” geometry. Chicane magnets located in the straight section generate the required X-ray beam separation. Operating a new lattice in which the straight section quadrupole triplets (QD3-QF2-QD1 and QD6-QF7-QD8) are replaced by doublets would make it possible to free maximum space in the straight sections and minimise the impact of shorter IDs on brilliance. This is sketched in Figure 1.

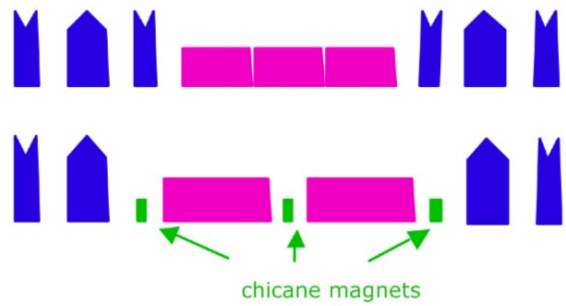

Figure 1: Straight section configuration of the nominal and new optics

A number of constraints are put on the design of the new optics:

i) Provide emittances and beam sizes identical to those of the nominal optics, as shown in Table 1. The main difference between the two optics is the reduction of the vertical tune by one integer.

Table 1: Comparison of the new and the nominal optics

	ε_x (nm)	High β_x (m)	High β_z (m)	Low β_x (m)	Low β_z (m)
New	4.0	37.7	2.9	0.35	3.0
Nominal	3.7	35.1	2.51	0.50	2.73

ii) Keep the gradients and the currents of the associated power supplies within their design range. For the quadrupoles, all currents (except QD6 which has the higher saturation) are reduced (Figure 2).

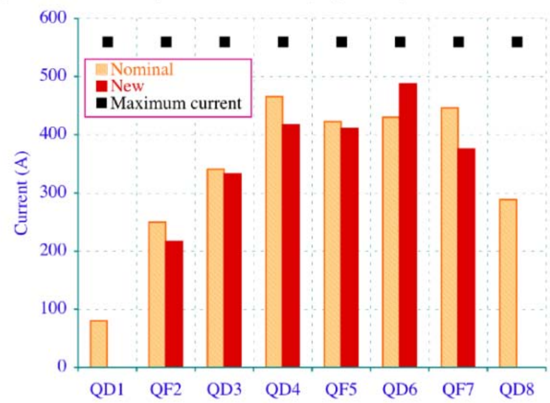

Figure 2: Quadrupole currents

For the sextupoles, the critical elements are the achromat sextupoles S13 and S19, which mainly act on the chromaticity (Figure 3). The requirements for both families (specially in the time structure filling patterns for which the chromaticity over-compensation is very large) bring them above the maximum currents of the power supplies. The temporary solution for the commissioning of the optics consists in connecting S19 to the Super

Spare Power Supply and in decalibrating the S13 power supply.

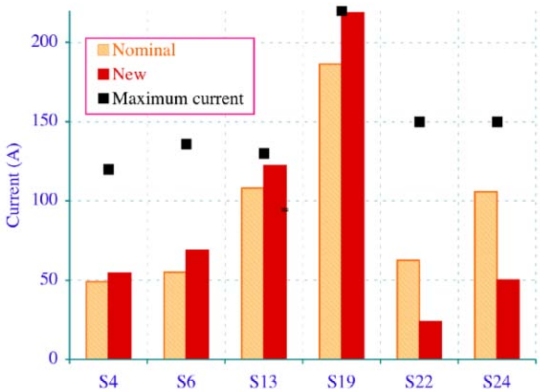

Figure 3: Sextupole currents

As shown in Figure 4, the differences in the optical functions of the new and nominal lattices are small.

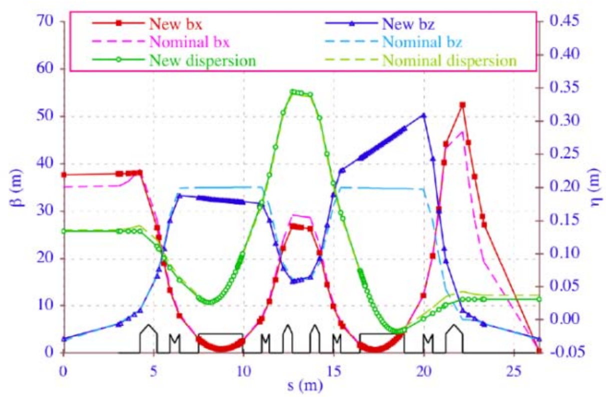

Figure 4: Optical functions of the two optics

COMMISSIONING OF THE NEW OPTICS

Performances

For the time being, a very limited number of shifts have been devoted to the testing of the new optics in multibunch mode. However results are very encouraging. The first stored beam could only be obtained by an empirical tuning of all available parameters (beam steering, tune adjustment, harmonic sextupoles tuning…). But then tests went on very smoothly. Comparative performances with the nominal optics at the beginning of Run 03-06 in 2 * 1/3 filling mode are summarised in Table 2 and the main achievements reviewed in the following sections.

Table 2: Compared performance of the new and nominal optics (theoretical emittances are in brackets and italics)

	New optics	Nominal optics
Injection efficiency (%)	68	70
Lifetime @200 mA (h)	43	46
Horizontal emittance (nm)	5.5 *(4)*	4.6 *(3.7)*
Vertical emittance (pm)	20	19

Analysis of the linear optics

In order to extract the quadrupole strengths of the perfect machine, a measured response matrix is reduced by averaging similar steerers with an adequate circular permutation of BPM readings. The resulting 224x6 matrix is fitted by varying the strengths of the 6 quadrupole families.

Apart from QD6, which has the largest deviation from the standard lattice and the highest saturation, the fitted values are very close to the desired values The tunes given by this model are 36.76/13.03, as compared to the expected values of 36.44/13.39. After installation of the measured response matrix, the rms closed orbit was brought to 88 μm (H) and 108 μm (V).

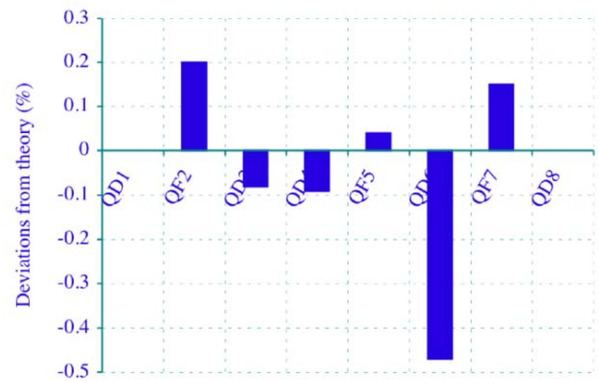

Figure 5: Differences between fitted and theoretical quadrupole strengths

A partial matrix is used to derive a model of focusing errors. The horizontal and vertical responses to a couple of H and V steerers are fitted by varying the strengths of the 320 quadrupoles using an SVD method. The same process is repeated for 16 pairs of steerers. The number of Eigen vectors in the fit is adjusted to obtain the minimum deviation between the 16 sets of quadrupole errors, and the error model is taken as the average of the 16 sets. Results for the bare machine and for the corrected machine (after correction of the sum and difference coupling resonances, horizontal and vertical half-integer resonances close to the working point) are shown in Figure 6 and Figure 7. Adding the resonance correction on top of the pre-computed correction of the half-integer resonances introduced a strong modulation in the vertical plane (15.9 %), as compared to 4.9 % in the horizontal plane.

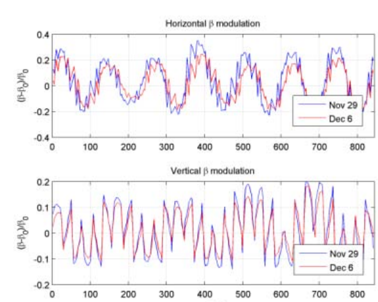

Figure 6: Modulation of the bare machine

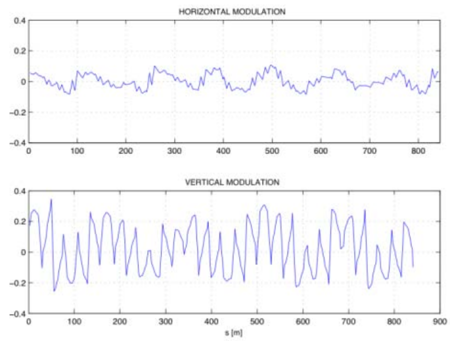

Figure 7: Modulation of the corrected machine

Aperture measurements

The on and off-momentum 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 by making the measurements as a function of an artificial aperture limit defined by closing the internal jaw of a scraper. Results are shown in Figure 8. The reduction of the on-momentum aperture by about 2 mm should be mastered once the harmonic sextupoles pattern is fully optimised. The dip in the horizontal aperture occurring around -1 % is a common feature of both optics. It is due to the fact that the particle tune path is crossing a node of third-order resonances around 0.33/0.33.

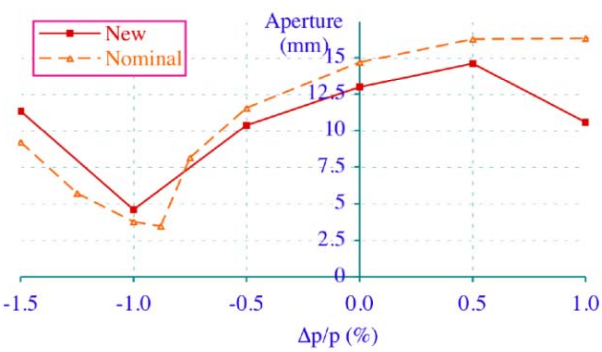

Figure 8: Comparison of the measured horizontal apertures of the new and nominal optics

Influence of resonance correction on machine performance

The correction of resonances (coupling resonances to bring the coupling down to 0.7 %, half-integer resonances and horizontal third-integer resonance to minimise the modulation and enlarge the Touschek lifetime) has always been part of the tuning strategy of the ESRF storage ring. For the new optics, the correction of a new sextupolar resonance $\upsilon_x + 2\ \upsilon_z = 63$ is essential for obtaining a correct lifetime, as illustrated in Figure 9.

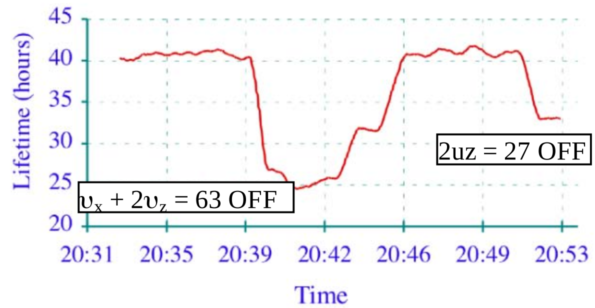

Figure 9: Influence of resonance correction on lifetime

Non linear characteristics

Tune shifts with momentum are measured by shifting the RF frequency. A good agreement with predicted values is obtained (Figure 10). Preliminary measurements of tune shifts with amplitude have also been performed using the turn-by-turn BPM system, one injection kicker and a vertical kicker (Figure 11).

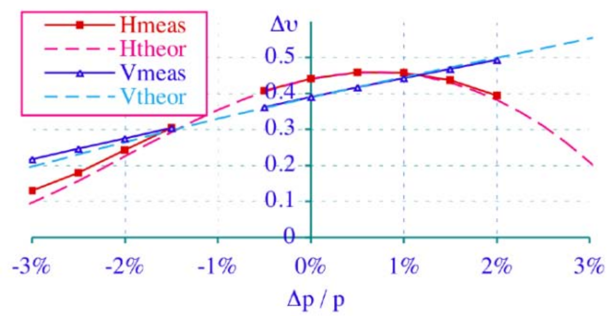

Figure 10: Tune shifts with momentum

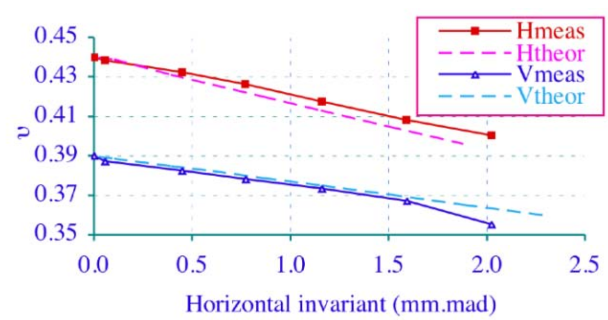

Figure 11: Tune shifts with amplitude

CONCLUSIONS

The tuning of a new optics for the ESRF storage ring is progressing satisfactorily. Once its behaviour in time-structure modes is assessed, this optics could be run in routine operation. Future plans to further increase the available space for the IDs involve the use of the dipolar correctors in the sextupoles to generate the chicane and the replacement of long quadrupoles by shorter ones.

ACKNOWLEDGMENTS

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