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ORBIT, OPTICS AND CHROMATICITY CORRECTION FOR PS2 NEGATIVE MOMENTUM COMPACTION LATTICES

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Abstract

The effect of magnet misalignments in the beam orbit and linear optics functions are reviewed and correction schemes are applied to the negative momentum compaction lattice of PS2. Chromaticity correction schemes are also proposed and tested with respect to off-momentum optics properties. The impact of the correction schemes in the dynamic aperture of the lattice is finally evaluated.

INTRODUCTION

The replacement of the aging Proton Synchrotron at CERN with a new ring (PS2) is a key element in the injector upgrade strategy for exploiting the full physics potential of LHC [1]. The 1346.4 m long ring with racetrack shape will avoid transition energy, as the ring's lattice is tuned to provide Negative Momentum Compaction (NMC) [2]. Among the different correction packages for controlling and reducing the effect of magnet errors and misalignments, particularly important are those for orbit and chromaticity control. The efficiency and performance of these two correction systems is being evaluated. For the chromaticity correction, particular emphasis is given to the induced off-momentum optics distortion and the impact to the dynamic aperture (DA).

ORBIT CORRECTION

56 horizontal and 54 vertical correctors for a total of 110 beam position monitors are distributed around the ring, adjacent to quadrupoles, in order to take advantage of the local beta function peaks. The corrector length is 30cm while the monitors are 10cm long. In all the studies, the nominal optics of the NMC ring are used with the working point at $(Q_x, Q_y) = (13.25, 8.21)$. Random errors, including relative dipole field distortion, transverse quadrupole and longitudinal dipole shifts and dipole tilts around the beam axis, are distributed around the ring with a Gaussian cut at 3σ. Their magnitude is chosen following the experience from the PS or similar synchrotrons. The rms values of the errors are displayed in Table 1 along with average maximum displacement of their individual contribution for 50 random machines. The maximum effect of the average displacement is around 9mm, a typical value observed at the PS before correction.

For the orbit correction, the CORRECT module in MADX [3] was used with the MICADO (most effective corrector) algorithm [4]. 100 correctors out of 110 were randomly chosen and a failure of 5% of the monitors was simulated. Only one third of the total number of correctors is necessary, although, different sets are used for the different machines. The orbit is corrected by a factor of 25 with a resulting average maximum displacement of around 0.5mm which is considered to be a relatively small orbit

Table 1: Error sensitivity of the NMC lattice for a sample of 50 machines.

Error	RMS value	$\langle(\Delta x/\Delta y)_{\max}\rangle$ [mm]
Rel. dipole field error	$5 \cdot 10^{-4}$	8.8 / —
Trans. quad. shift	0.2 mm	8.8 / 8.6
Long. dipole shift	0.3 mm	0.3 / —
Dipole tilt	0.3 mrad	— / 5.4

Table 2: Average maximum and rms orbit distortion before and after correction, for a sample of 500 random seeds.

	Before correction		After correction	
	Δx	Δy	Δx	Δy
$\langle(\Delta)_{\max}\rangle$ [mm]	13.6	11.6	0.5	0.4
$\langle(\Delta)_{\rm rms}\rangle$ [mm]	5.2	5.0	0.2	0.1

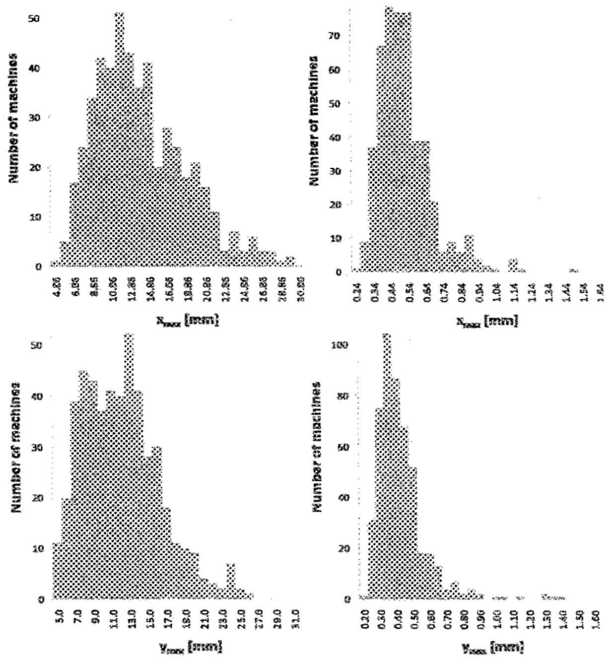

Figure 1: Distribution of the maximum orbit deviation at the horizontal (top) and vertical plane (bottom), before (left) and after correction (right).

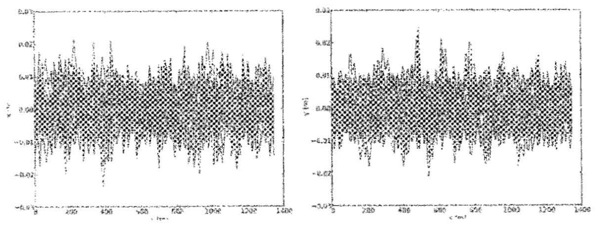

Figure 2: Orbits before (blue) and after correction (red) for the horizontal (left) and vertical plane (right).

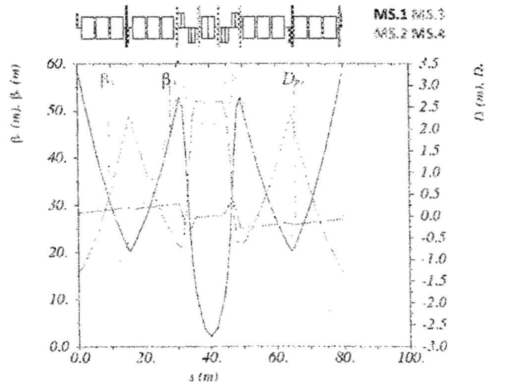

Figure 3: Optics of the NMC module with the positions of the four chromaticity sextupole families.

deviation for machine operation. Fig. 1 presents the distribution of the maximum orbit deviation in the horizontal and vertical plane, before and after correction. The distribution sharpens around the average of 0.4-0.5mm after correction and less than 1% of the machines exceed 1mm maximum orbit distortion. The good efficiency of the correction is also visible in Fig. 2, where the orbits from 30 machines are displayed, before and after correction. Note that the obtained corrector kicks do not rise above 0.2mrad which results in a bending field of around 0.12T. As the available drift space is tight and the quadrupole strengths high, one may foresee to cut the corrector length down to 20cm by increasing the maximum field to 0.2T.

CHROMATICITY CORRECTION

The chromaticity is controlled by a set of 40cm-long sextupoles placed in the NMC module in a way that they take advantage of the peaks on the beta functions and dispersion, as shown in Fig. 3. They may form up to 4 families with 2 symmetric members, apart from MS.4 which has only one member as the symmetric position is taken by an orbit corrector. Three correction schemes have been tested. The simplest one is using two families to correct only chromaticity by connecting in series the two symmetric central sextupoles (MS.2 and MS.3). A second variant is formed by connecting in series MS.1 with MS.3 and MS.2 with MS.4. The MS.1 and MS.4 have opposite polarities with respect to MS.1 and MS., as the dispersion in these location has opposite sign. The last scheme is by using all four families powered individually and in principle is able to correct two more parameters.

For the chromaticity correction, the matching module of MADXPTC [3] is used. All schemes are able to set the chromaticity to zero. The last one is also attempting to reduce the horizontal and vertical off-momentum beta-beating. The maximum normalized sextupole strength is 0.25m^{-2}, which translates to 0.5T at top energy and 7cm pole tip. The effect of the sextupoles in the off-momentum beta beating is presented in Fig. 4. In all the plots , the maximum and rms value of the horizontal and vertical beta variation is displayed over a range of momentum spreads, from -1% to +1%. The top left plot corresponds to the uncorrected case. At momentum spreads close to 1% the horizontal beta beating becomes very large due to the approach of the integer tune $Q_x = 13$. After correction the horizontal beating is significantly reduced for all 3 schemes and the vertical peak value is slightly increased to about 25%. Actually the 4-family scheme, which is supposed to correct also the beta beating, affects mostly the vertical plane.

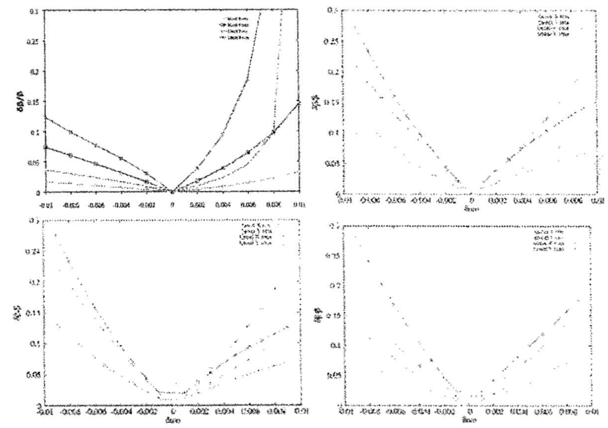

Figure 4: Off-momentum beta beating before (top left) and after chromaticity correction, for the 3 schemes, using only the two central sextupole families (top right), connecting all sextupoles in two families (bottom left) and using all four families (bottom right). The curves correspond to horizontal maximum (blue) and horizontal rms (red), vertical maximum (purple) and vertical rms beta beating (green).

The off-momentum beta beating estimation before and after correction suggests that the 2nd order chromaticity is not affected by the inclusion of chromaticity sextupoles. The variation of the horizontal and vertical tune with momentum displayed on the tune diagram, can be found on the left of Fig. 5. The curves correspond to different sextupole correction schemes and the momentum varies from -1% to 1%. The green curve corresponding to the scheme where only MS.2 and MS.3 are used presents the larger tune-shift with momentum. Even in this case, the maximum tune-shift is around 6×10^{-3} in the horizontal and 12×10^{-3} in the vertical plane. In the other two schemes the 2nd order chromaticity is reduced by more than a factor of two.

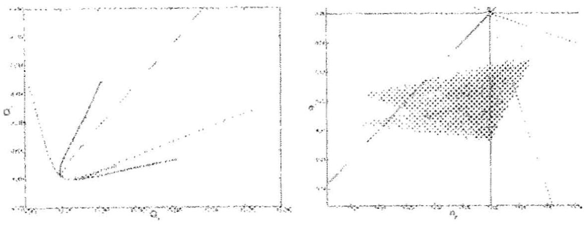

Figure 5: Tune-shift with momentum spread from -1% to 1% (left) and first order tune-shift with amplitude up to 10σ and zero momentum spread (right) for the different chromaticity correction schemes, using only the two central sextupole families (green), connecting all sextupoles in two families (purple) and using all four families (blue).

IMPACT TO NON-LINEAR DYNAMICS

The sextupoles introduce non-linear fields and may reduce the DA. The first order detuning with amplitude is shown in the tune diagram for amplitudes of up to 10σ in the right plot of Fig.5, for the different sextupole schemes. The resonant lines up to 4th order in the vicinity of the working point are also traced. The red lines are systematic resonances, blue are random and the full and dashed lines represent normal and skew resonances. The evaluation includes the leading order effect of magnet fringe-fields which is sextupole-like in the dipoles and octupole-like in the quadrupoles [5], both inducing a linear tune-shift with the action. The tune-shift with amplitude in all 3 cases is of the order of 5×10^{-2} at 10σ. The smallest footprint corresponds to the case of all sextupoles connected in 2 families (purple). The only resonance crossed by the other two tune footprints (2 central sextupoles only and four families) is the coupling $(1,-1)$ which corresponds also to the 4th order $(2,-2)$ resonance, excited at first order by quadrupole fringe fields and to 2nd order by sextupoles.

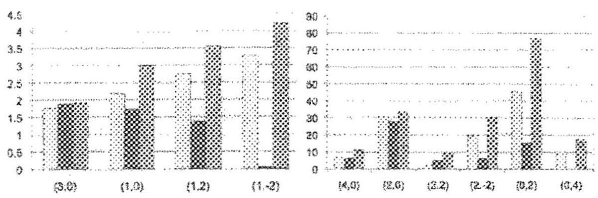

Figure 6: Amplitude of 3rd (left) and 4th order (right) resonance driving terms for the different chromaticity correction schemes, using only the two central sextupole families (blue), connecting all sextupoles in two families (red) and using all four families (yellow).

Another indication of the induced non-linear effects is the 3rd and 4th order Hamiltonian resonance driving term amplitudes (Fig. 6). The different bar colors correspond to the various chromaticity sextupole arrangements. The smallest impact comes from the scheme using only 2 sextupole families (blue bars) and the largest corresponds to the 2 family scheme with all systematic sextupoles connected in series, although the final performance may be heavily influenced by the choice of the working point and amplitude detuning.

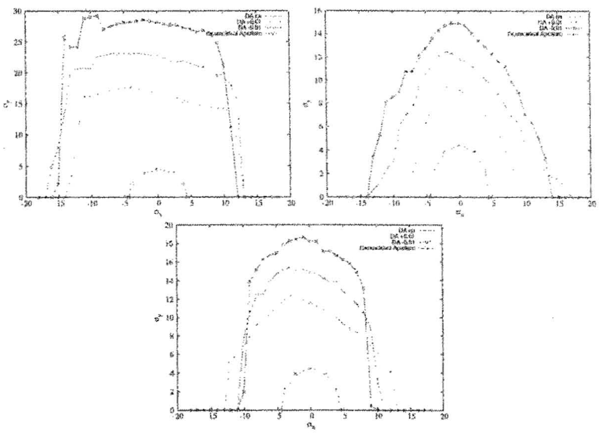

Figure 7: Horizontal versus vertical dynamic aperture in σ for the 3 sextupole schemes, using only the two central sextupole families (top left), connecting all sextupoles in two families (top right) and four families (bottom). Different curves correspond to 1% (blue), -1%(green), and zero momentum spread (red) and the geometrical aperture (purple).

The resonance driving terms amplitudes are well correlated with the DA, after tracking particles in 5D for 1000 turns with MADXPTC [3]. The different curves correspond to 1% (blue), -1% (green), and zero momentum spread (red) and the geometrical aperture is traced in purple. The 2 central sextupole scheme shows the largest DA (especially in the vertical plane) followed by the 4 family scheme and the 2 families with all symmetric sextupoles in series. All the schemes provide a conformable DA as compared to the physical aperture.

In conclusion, the orbit and chromaticity correction do not represent major challenges for the dynamics of the PS2 NMC ring. Both correctors may be reduced in size (steerers) or number (chromaticity sextupoles) in order to increase the available drift space for other equipment or the length of the adjacent quadrupole magnets and thereby enlarging the tunability of the lattice. Detailed non-linear dynamics studies are in progress to evaluate the interplay between space-charge and magnetic non-linearities.

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