COMPARISON OF PS2 LATTICES WITH DIFFERENT GEOMETRIES

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Abstract

The PS2 ring is designed with Negative Momentum Compaction (NMC) arc cells and doublet straights. In this paper, different lattice geometries are considered. In particular, a two-fold symmetric lattice with dispersion suppressors and a 3-fold symmetric one with resonant arc cells are compared with respect to their optics properties and ability to satisfy space and magnet constraints. The tuning flexibility of rings based on these two options is presented. Finally, the impact of different geometries on resonance excitation and dynamic aperture is evaluated.

INTRODUCTION

As part of a possible upgrade scenario of the CERN injector complex, the replacement of the existing PS synchrotron by a new machine called PS2 is currently under study. In order to avoid crossing of the transition energy it was decided to design a lattice with imaginary γ_t, i.e. negative momentum compaction (NMC) factor. The PS2 should provide the same flexibility for handling different kind of beams as the PS but with higher intensity and significantly higher extraction energy of about 50 GeV. In order to account for space charge effects due to higher beam intensities, the injection energy of the protons is set to 4 GeV. For achieving an optimized filling pattern of the subsequent SPS, the circumference of the PS2 is fixed to 1346.4 m (15/77 of the circumference of the SPS). Based on integration aspects of the PS2 into the existing injector complex at CERN, it was proposed to include injection and extraction channels in the same long straight section. While the nominal lattice of the PS2 is based on a racetrack shape [1], alternative lattices with a three fold symmetry should be investigated as the number of systematic resonances decreases with higher super-periodicity. Of particular interest are thereby lattices with resonant [2] arc cells due to the compactness of the arcs (no dispersion suppressors are needed) and the local cancellation of resonance driving terms per arc. In order to have a direct comparison between different lattice solutions, the current doublet long straight section (LSS) design [3] with a length of 107.8 m should be used in all studies. In addition, the minimum magnet to magnet drift space should be 0.8 m for dipoles and 1.3 m for quadrupoles to allow for the installation of chromaticity correction sextupoles, beam position monitors, orbit correctors, vacuum pumps and beam instrumentation equipment. The PS2 design study is based on conventional, separated function magnets with a maximum bending field of 1.7 T and a maximum gradient of 16 T/m. A summary of the main lattice design constraints is given in Table 1.

Table 1: PS2 lattice design constraints

Parameter	Value
Injection energy, kinetic	4 GeV
Extraction energy, kinetic	50 GeV
Circumference	1346.4 m
Transition energy	imaginary
Maximum bending field	1.7 T
Maximum quadrupole gradient (arc)	16 T/m
Minimum drift space, dipoles	0.8 m
Minimum drift space, quadrupoles	1.3 m

TWO FOLD SYMMETRIC PS2 LATTICE

The nominal lattice of the PS2 is based on a racetrack shape with 5 basic NMC cells and two dispersion suppressor modules per arc. Since this type of lattices allows for high flexibility in the arcs, the tuning of the working point is mainly achieved by changing the phase advance in the NMC cells and matching the dispersion suppressor to the straight section. Figure 1 shows the optics functions for the working point $(Q_x, Q_y) = (11.8, 6.71)$ with $\gamma_t = 26i$ in one quarter of the ring. A total of 170 dipoles with a length of 3.7 m is distributed along the arc, 10 of them in each dispersion suppressor module and 13 in each NMC cell. Three different types of quadrupoles with lengths of 0.8 m, 1.6 m and 2.2 m are used in the arcs. A fourth type with wider aperture is needed in the LSSs for accommo-

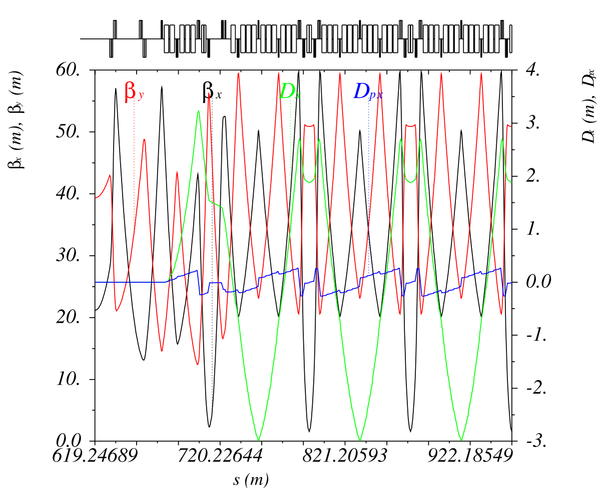

Figure 1: Optics functions for one quarter of the PS2 ring, tuned to the working point $(Q_x, Q_y) = (11.81, 6.71)$.

dating high amplitude trajectories during injection and extraction. The quadrupoles in the NMC cells are grouped to 4 families, while 6 independently powered quadrupoles are needed in the dispersion suppressor module to achieve the matching constraints. The magnet to magnet drift spaces meet the requirements all along the arc. A study on the tuning flexibility of this lattice [1] shows that the working point can be adjusted between 10.5 and 12.5 in the horizontal plane and between 6 and 9 in the vertical plane with γ_t varying from 18i to 50i without changing the optics in the LSS.

ALTERNATIVE LATTICES

Two different solutions for a three-fold symmetric lattice with resonant arcs are considered as possible alternatives to the racetrack shaped PS2 lattice. The first candidate solution presented here consists of 5 basic NMC cells per arc. Each of the arcs is tuned to a horizontal phase advance of $\mu_x = 4 \cdot 2\pi$ for suppressing dispersion at their end. Although, strictly speaking, the "resonant lattice concept" [2] should include an even number of cells $2M$ and an odd arc tune $2M - 1$ for better suppression of resonant driving terms induced by sextupoles, we deviate from this concept due to the PS2 space constraints. Three different types of quadrupoles with lengths of 1 m, 1.4 m and 2.4 m are needed for efficient operation of the 4 families in the arcs. A good filling factor of the basic NMC cell is achieved by reducing the number of dipoles per cell to 9. Keeping the nominal values for the required magnet-to-magnet drift spaces limits the length of the 135 dipoles to 4.31 m, which translates to a kinetic energy of 46.3 GeV considering a maximum bending field of 1.7 T.

Since the horizontal phase advance of the arc is fixed by the resonance condition, the contribution to the tuning flexibility of the arc is limited to the vertical plane. Therefore, the horizontal tune of the machine has to be adjusted with the long straight sections. The tunability of the latter is however limited by the phase advance constraints set by the beam transfer elements and the optical functions at the beginning being fixed by the arc. Since the tuning range of the long straight section is centered around $\mu_x = 0.75 \cdot 2\pi$, the natural horizontal tune is $Q_x = 14.25$. The vertical tune on the other hand is much more flexible. Figure 2 shows a plot of the optics functions for one super-period of the ring tuned to the working point $(Q_x, Q_y) = (14.22, 7.2)$, with $\gamma_t = 41i$ and natural chromaticities of $\xi_x = -18$ and $\xi_y = -13$. Note that the β-functions have significantly smaller peak values compared to the nominal racetrack lattice. However, due to the resonant behavoir of the arcs, the oscillation of the dispersion function D_x reaches much higher values. Calculating the geometrical acceptance for the high emittance fixed target beam ($\epsilon_x = 9\pi$ mm mrad, $\epsilon_y = 6\pi$ mm mrad normalized emittances) in the same way as for the nominal lattice [1], 2.95σ of beam size fit into the vacuum chamber of the PS2. This value appears small compared to 3.6σ obtained for the racetrack lattice.

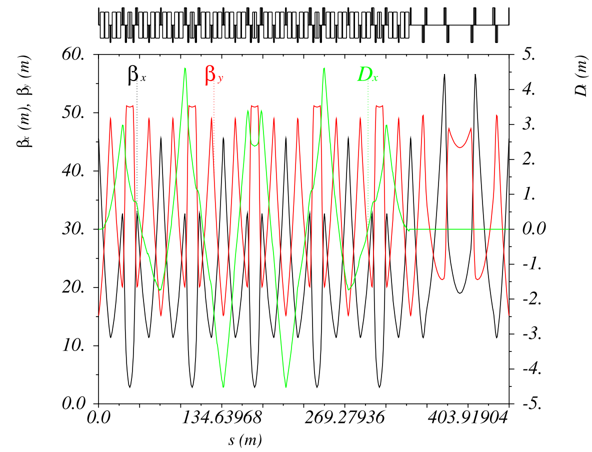

Figure 2: A super-period of a three-fold symmetric resonant lattice for PS2, tuned to $(Q_x, Q_y) = (14.22, 7.2)$ with $\gamma_t = 41i$.

A GLASS study on the tuning flexibility of this lattice alternative is performed similar to the one reported in [1]. Three quadrupole gradients in the basic NMC cell are varied systematically, while the horizontal phase advance is tuned to $\mu_x = 0.8 \cdot 2\pi$. In addition, two quadrupoles of the straight sections are varied and the remaining two are used to match the optics to the arc cells. All solutions with maximal β-functions below 67 m and maximal gradients of 16 T/m are considered as valid. Note that, no restrictions for the phase advances in the straight sections are taken into account. Figure 3 shows the resulting values of γ_t as a function of the transverse tunes Q_x and Q_y. The tuning flexibility is very limited in the horizontal plane with Q_x ranging from 13.95 to 14.5. This range may be reduced even further by imposing beam transfer constraints. On the other hand, the vertical tune can be adjusted between $Q_y = 5.5$ with $\gamma_t \approx 50i$ and $Q_y = 10$ with $\gamma_t \approx 28i$.

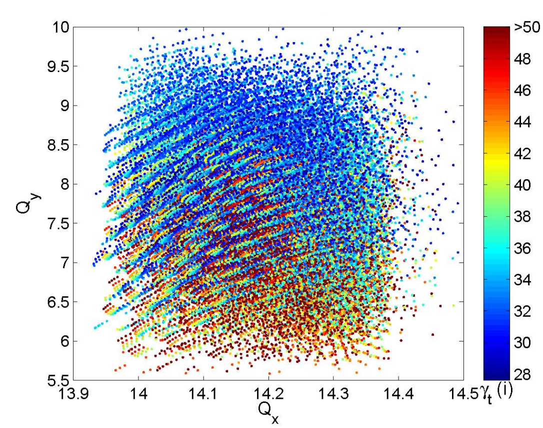

Figure 3: Tuning flexibility of the three fold symmetric NMC lattice alternative. The color-code shows values of γ_t for all the possible solutions found in the GLASS study.

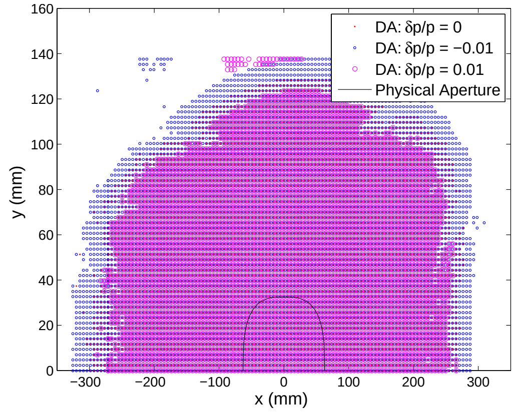

Figure 4: Plots of the dynamic aperture for $\delta p/p = -1\%$, $\delta p/p = 0$ and $\delta p/p = +1\%$ for the first solution.

A first study on the chromaticity correction is performed using a simple two family scheme: Four sextupoles are installed in each basic NMC cell around the quadrupole doublets, resulting in a total of 60 magnets. A rough indication on the beam dynamics is obtained from dynamic aperture simulations, where particles are tracked for 1000 turns in 5D using the MADX-PTC module. Figure 4 shows plots of the dynamic aperture for the three cases of $\delta p/p = -1\%$, $\delta p/p = 0$ and $\delta p/p = +1\%$ in comparison with the physical aperture. The frequency map analysis presented in Fig. 5 explains the huge size of the dynamic aperture, which is even larger than the one of the nominal lattice [4]: Although high order resonances are clearly visible in the frequency map, they have small amplitudes and do not lead to particle loss. Especially the (4,0) systematic 4^{th} order resonance at $Q_x = 14.25$ does not impose a limitation on the dynamic aperture. Interestingly, the separated area in the diffusion map containing particles with amplitudes above $y = 14$ cm corresponds to particles trapped by the half integer resonance at $Q_y = 7.5$.

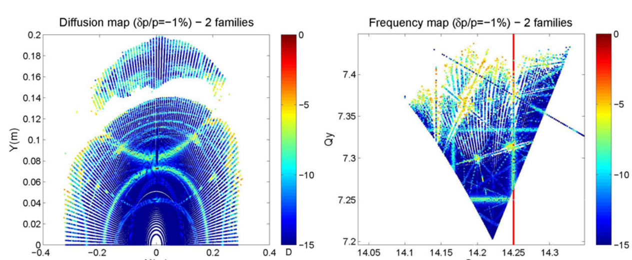

Figure 5: Diffusion map (left) and frequency map (right) for the threefold symmetry lattice with $\delta p/p = -1\%$.

The second lattice solution is based on NMC modules built with FODO cells, similar to the J-Parc 50 GeV ring [5]. Each module is composed of 3 DOFO cells containing 10 dipoles and 4 families of quadrupoles of 2 types with a maximum gradient of 15 T/m. As in the previous threefold lattice, one arc is composed of 5 modules with a horizontal tune of 4 in order to achieve the achromatism. In order to respect the optics constraints, especially the required drift spaces around magnets and the long straight section lattice, the maximum bending radius has been decreased to 87.8 m which corresponds to a maximum energy of 45.5 GeV for a magnetic field of 1.73 T. A crucial difference with respect to the previous 3-fold symmetric alternative is that the NMC modules start with a defocusing quadrupole, and thus the matching to the LSS is achieved by adding another DOFO half-cell. The resonant condition and the beam transfer elements also induce a limitation on the tunability of the ring, especially for the horizontal plane. However, the betatron phase advance has been adjusted so as to cancel the dispersion function in the LSS, with $\gamma_t \approx 40i$, although some further tune optimization is needed. Figure 6 presents the optical functions obtained with BETA [6] for one super-period of the ring.

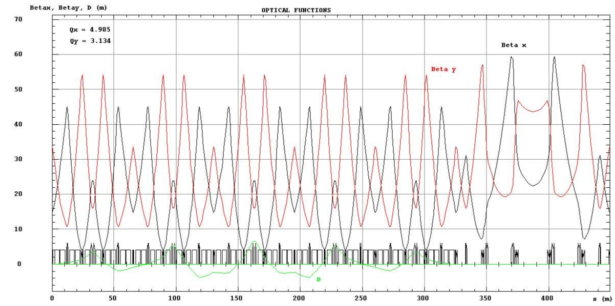

Figure 6: One super-period of a 3-fold symmetry PS2 lattice based on FODO cells.

In order to compensate the natural chromaticity of the ring, two scenarios of correction have been investigated. The first one is based on 2 and the second on 4 families of sextupoles located in dispersive regions of the ring. The off momentum beta-beat in both cases is moderate. The corresponding dynamic aperture has been computed using BETA for different values of $\delta p/p$ and is equally large as for the previous 3-fold symmetric lattice.

In summary, both alternative resonant 3-fold symmetric structures present good characteristics with respect to non-linear dynamics. On the other hand, they seem to be less tunable and to have smaller geometrical acceptance. Studying the effect of space charge is a necessary step for drawing final conclusion for the most favorable lattice geometry.

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