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PERIODICITY FIVE LATTICE PROPOSAL FOR A CPEDM PROTOTYPE RING

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Abstract

The community studying facilities to measure a possible Electric Dipole Moment of a charged particle (cpEDM) in a storage ring agreed that a Prototype Storage-Ring (PSR) is required as intermediate step to address critical questions, gain experience and rule out showstoppers. In what follows, a new lattice proposal of the PSR with a periodicity five is described and spin tracking simulations are shown. The main feature of this new lattice proposal is to use weak focusing quadrupolar components to achieve vertical stability, while the horizontal optics properties are dominated by the focusing from the bending elements, with a little impact from the quadrupoles.

INTRODUCTION

Extensive studies have been done first on a weak focusing version [1] and later on strong focusing versions [2, 3] of such a cpEDM ring. Common to all proposals with electrostatic quadrupoles is that the average radial magnetic field is a severe limitation of the sensitivity, i.e., the smallest Electric Dipole Moment (EDM) that can be discovered. The assessment of these unwanted radial magnetic fields by a measurement of the vertical orbit separation, enhanced by operation with very low vertical tune, is foreseen as mitigation measure. In case of the weak focusing scheme, this implies operation with very weak gradients superimposed to the deflecting electric fields.

Despite extensive studies, many uncertainties persist as, e.g., maximum electric fields feasible in a large installation, the feasibility of the scheme to assess the average magnetic fields, achievable spin coherence times and sensitivity limitations in general. Thus, the community agreed that a Prototype Storage-Ring (PSR) is required as intermediate step. First PSR lattices proposed [3] had fourfold symmetry and allowed stable lattices with strong quadrupole strengths. However, the proposed geometry did not allow to obtain a stable machine with weak vertically focusing quadrupoles to test operation similar to the weak focusing EDM ring proposals. The underlying reason is the horizontal overfocusing in bendings leading, with the low periodicity and given length of straight sections, to an unstable lattice in the horizontal plane. A proposal to overcome this limitation is to increase the bending radius leading to a significant increase of the machine size and low electric field. This implies higher cost and is in conflict with operation with high electric fields.

A fivefold symmetry lattice is proposed in order to overcome the limitations of the fourfold PSR ring proposals. Such a machine with fivefold symmetry allows two operational modes: one with only very weak vertically focusing quadrupoles and the other with strong quadrupoles and higher (horizontal) tunes.

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PERIODICITY FIVE LATTICE WITH BENDING RADIUS OF 7.2 M

The lattice described in this section has a bending radius ρ of 7.2 m and half the circumference of the COoler SYnchrotron (COSY) at FZ-Julich (Germany). With an electric deflecting field of 7 MV/m, this allows a beam energy of 25.538 MeV for purely electrostatic operation and 37.034 MeV for frozen spin operation with, in addition, a vertical magnetic field of 0.03779 T. The ratio between bending length to straight section lengths is reduced significantly. Still, stable lattices are possible with very weak vertically focusing quadrupolar components. For this mode of operation and only electric fields, the horizontal tune is above 2, which works well with the higher periodicity. The main parameters for the PSR proposals presented are given in Table 1 based on reference [3]. The geometry of one period is shown in Fig. 1. Working points are shown in Fig. 2. The lines correspond to weak vertically focusing quadrupolar components (k<0) of one quadrupole family to achieve vertical stability. The horizontal optics properties are dominated by the focusing from the bending elements with little impact from the quadrupoles. The red and green lines are for frozen spin and electrostatic operation, respectively. The solid and dashed lines are for finite quadrupole strenghts of quadrupole family QE and QC, respectively. The dots correspond to the quadrupole settings (case a, b, c and d) listed in the lattice properties (see Tables 2 and 3).

Simulation Results for Electrostatic Beam Operation

In Table 2 selected lattice properties are listed and in Fig. 3 the Twiss parameters for all the different cases are shown for the electrostatic beam operation. The results

Table 1: Basic Parameters for the Periodicity Five PSR Lattice

Basic parameters [unit]	E only	E&B frozen spin
Bending radius ρ [m]	7.20	7.20
Circumference C [m]	91.79	91.79
Kinetic Energy E_k [MeV]	25.538	37.034
relativistic $\beta = v/c$	0.2287	0.2730
relativistic γ	1.02722	1.03947
Momentum p [MeV/c]	220.4	266.2
Electric field E [MV/m]	7.00	7.00
Magnetic field M [T]	0	0.03799

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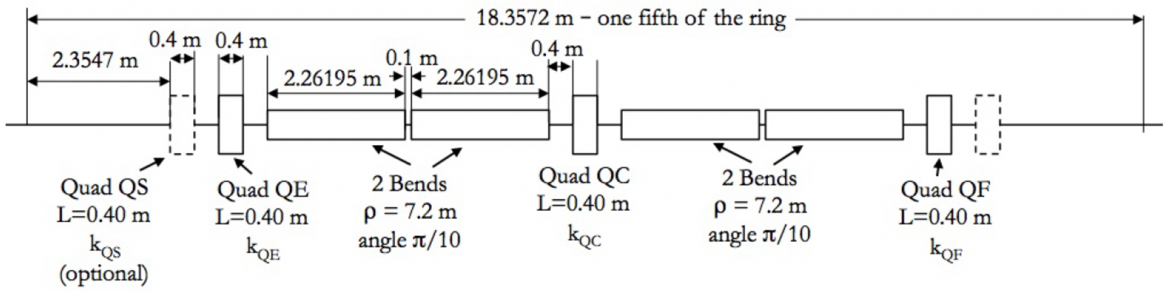

Figure 1: Geometry of one fifth of the periodicity five PSR lattice with bending radius of 7.20 m.

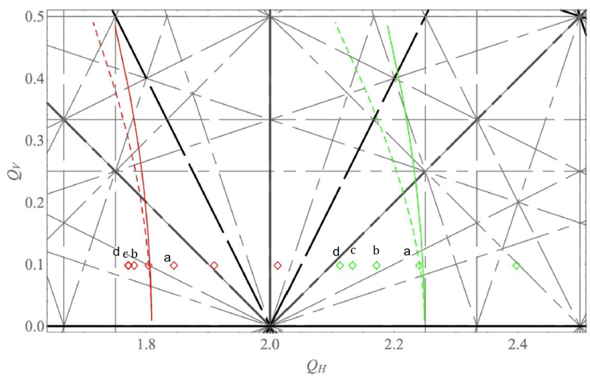

Figure 2: Working points for some of quadrupole settings of the periodicity five PSR lattice.

Table 2: Selected Settings and Lattice Parameters Obtained with the Periodicity Five PSR Lattice and Electrostatic Operation

Parameter	Settings			
	a	b	c	d
QE int. gradient (m^{-1})	-0.02	0.02	0.04	0.06
QC int. gradient (m^{-1})	0.0396	-0.0403	-0.0753	-0.1075
Q_H	2.398	2.172	2.133	2.113
Q_V	0.100	0.100	0.100	0.100

have been obtained with BMAD tracking code [4]. For this specific case, in order to see if the spin tracking has been performed correctly, an evaluation of the spin tune has been done and then compared with analytical estimates. In fact, from analytical estimates the the spin tune (for the purely electric case) is given by: $Q_S = G\gamma - (G+1)/\gamma$, with G = 1.17285 for protons, that is in this case -0.877191. From simulations, instead, the spin tune is evaluated as: $Q_S = -\alpha/2\pi = 1/2\pi \arccos(S_z) - 1$, that is -0.877191, with S_z= 0.7168057, that is the longitudinal component of the spin, and $\alpha = 2\pi$ - $\arccos(S_z)$. From this evaluation we can see there is a perfect agreement between analytical estimates and simulation results.

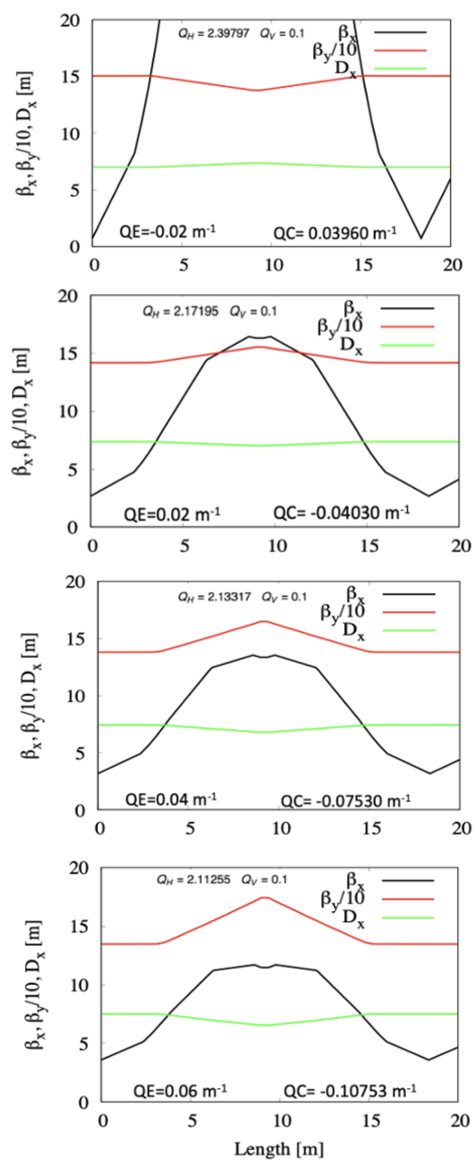

Figure 3: Lattice functions for some of quadrupole settings (case a, b, c, d from top to bottom, respectively) of the periodicity five PSR lattice and electrostatic operation.

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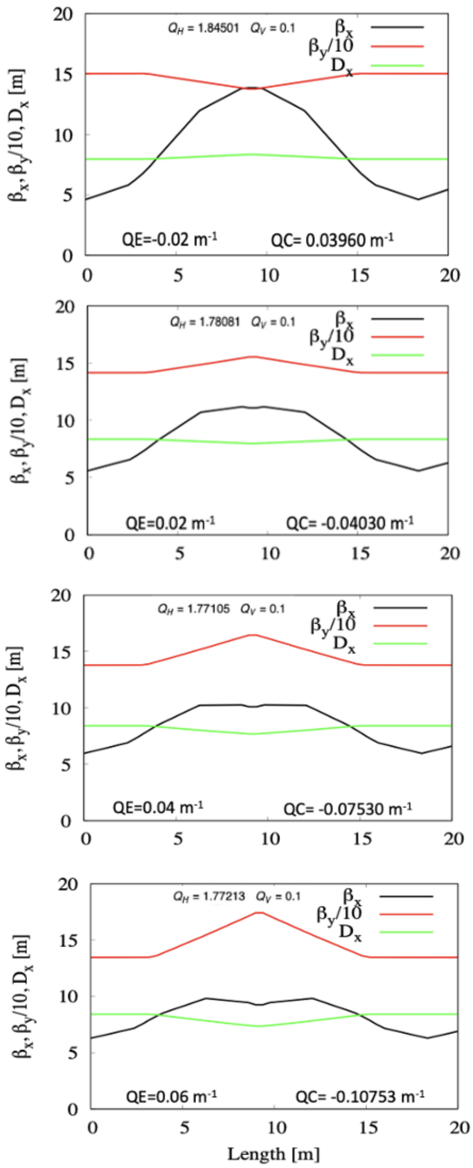

Figure 4: Lattice functions for some of quadrupole settings (case a, b, c, d from top to bottom, respectively) of the periodicity five PSR lattice and frozen spin operation.

Simulation Results for Frozen Spin Operation

In Table 3 selected lattice properties are listed and, in Fig. 4, the Twiss parameters for all the different cases are shown for the frozen spin operation. The results have been obtained with BMAD tracking code [4]. In Fig. 5 the results of the spin tracking can be seen. It is clearly visible that the frozen spin condition is satisfied for the periodicity five PSR lattice proposal.

CONCLUSION

Different quadrupole family settings for a periodicity five PSR ring have been studied and various scenarios for possible working points have been shown. Furthermore, functions and the spin tracking results performed with BMAD have been presented. The spin tracking simulation confirms that the frozen spin condition is perfectly satisfied. Possible operations with the all-electric ring as first step and then possible operations with frozen spin condition are compatible with the presented periodicity five lattice design.

The geometry has been adjusted to a circumference corresponding to half the one of COSY. In order to keep the length of the straight sections reasonable, the bending radius has been slightly decreased w.r.t. the fourfold symmetry PSR proposal reducing slightly the beam energies. Similar PSR designs with slightly increased sizes would allow to increase again the beam energies.

Table 3: Selected Settings and Lattice Parameters Obtained with the Periodicity Five PSR Lattice and Frozen Spin Operation

Parameter	Settings			
	a	**b**	**c**	**d**
QE int. gradient (m^{-1})	-0.02	0.02	0.04	0.06
QC int. gradient (m^{-1})	0.0396	-0.0403	-0.0753	-0.1075
Q_H	1.8450	1.7808	1.7711	1.7721
Q_V	0.100	0.100	0.100	0.100

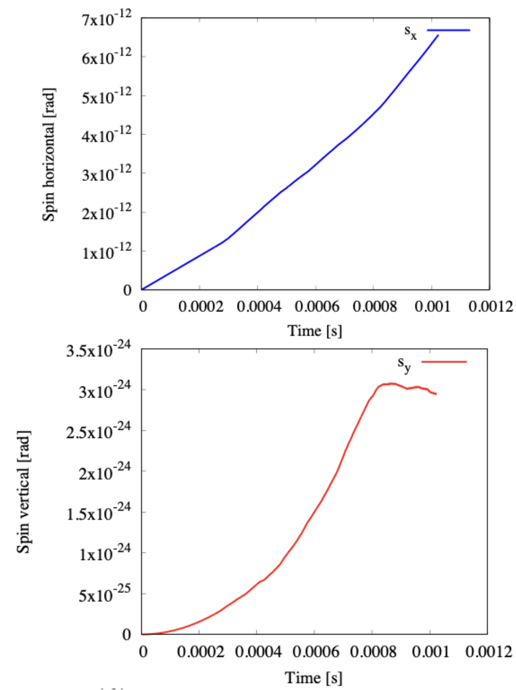

Figure 5: Horizontal (top) and vertical (bottom) spin build up respectively of the periodicity five PSR lattice for frozen spin operation.

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