OPTIMIZATION OF LOW EMITTANCE LATTICES FOR PETRA III

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Abstract

The reconstruction of the existing 2.3 km long storage ring PETRA II into a 3rd generation synchrotron light source (PETRA III) calls for an horizontal emittance of 1 nm rad. In addition the on- and off-momentum dynamic acceptance should be large to ensure sufficient injection efficiency and beam lifetime. We present three different types of lattices for the arcs of PETRA: a so-called TME lattice and a FODO lattice which both are newly designed to reach the specified emittance and the present FODO lattice with damping wigglers. The different lattice types have been compared through tracking calculations, including wiggler nonlinearities. Only the relaxed FODO lattice with damping wigglers meets the acceptance goals.

INTRODUCTION

The layout principles and parameters of the new PETRA III synchrotron light source are described in [1]. The basic idea is to reconstruct one to two of the PETRA octants (at the moment PETRA consists of 8 similar sections, so-called octants) to accommodate insertion devices. The remaining parts of the ring will not be used for synchrotron radiation, but they will determine the beam characteristics. Thus the optimisation of the accelerator layout depends crucially on the choice of the magnet lattice in these sections.

LINEAR OPTICS

The primary task of the linear optics design is to reach the required emittance of 1 nm rad. PETRA III will consist of different sections: the normal arcs (A), the new octant (N), undulators (U) and eventually damping wigglers (W). The parameters of the new octant are more or less fixed by user demands. The optimization of the remaining octants can be done by changing the phase advance and type of the lattice, decrease the bending angle per cell or insert damping wigglers to increase the synchrotron power radiated per turn.

The following optic variants have been investigated (see also Figure 1 to Figure 3):

a) The present hardware and 72° FODO cell lattice is kept. Additional damping wigglers have to be installed. First order sextupole resonances are cancelled in every octant after 2 times 5 FODO cells. The chromaticity of the new octant is corrected with the sextupoles in the old octant as well. These strong sextupoles and wiggler non-linearities will determine the dynamic aperture.

b) The existing magnets are regrouped to obtain a so-called minimum emittance lattice with the dipole centre being at the minimum of the horizontal beta and dispersion function of a cell. The phase advance is chosen to cancel the sextupole resonance terms within one octant. The dynamic aperture is restricted due to even stronger sextupoles (bad separation of the focussing and defocusing sextupole families).

c) Completely new magnets allow a new lattice to be built, which consists of short 90° FODO cells designed to reach the 1 nm rad emittance. Sextupoles get even stronger than in the previous case (small dispersion function).

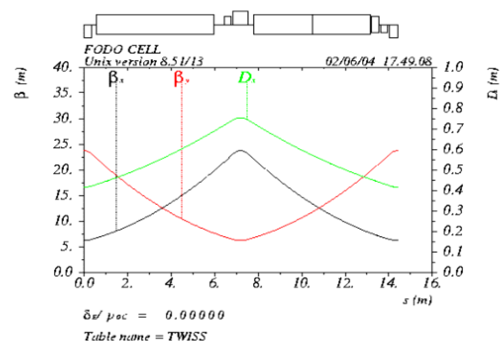

Figure 1: Existing 72° FODO cell with 3.2° deflection per cell.

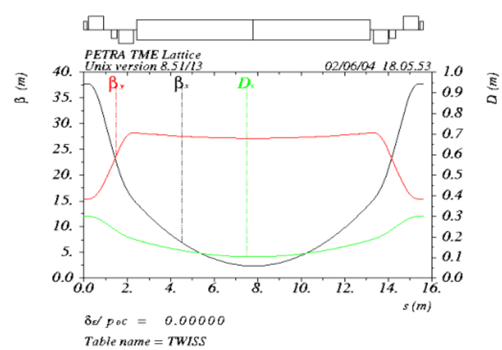

Figure 2: TME cell using existing magnets with 3.2° deflection per cell.

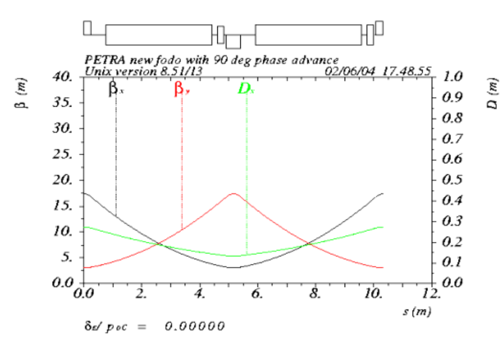

Figure 3: Short 90° FODO cell with 2.25° deflection per cell using new magnets.

DYNAMIC APERTURE

Non-linear Properties

The non-linear behavior of the lattices is determined by the chromaticity correcting sextupoles and the damping wigglers. No other non-linearities have been considered in these calculations. The chromaticity correction is performed globally in the old octants. The new octant and the other 6 straight sections have no chromaticity correction.

No harmonic sextupoles are considered. Contrary to synchrotron light sources with a huge number of identical cells and dispersion free sections PETRA consists of long arcs and provides only few spaces for additional non-chromatic sextupoles. Thus the sextupoles are distributed in the simplest possible fashion: 2 families in the TME and 90° FODO and 4 families in the 72° FODO.

Non-linear properties of the lattices have been checked with the six-dimensional tracking code SIXTRACK [2] including wiggler nonlinearities [3]. Post processing with frequency-map techniques allows detuning terms and resonances leading to diffusion [4] to be identified.

Figure 4 to Figure 6 show the frequency map in tune space for the three lattices. The color code corresponds to the normalized tune difference between the tune derived from the first resp. the last half number of turns $\log_{10}\left(\left|\nu_1 - \nu_2\right| / \#_{turns}\right)$ and is a measure of possible diffusion.

The various non-linear properties can be clearly identified: the 90° FODO lattice covers the smallest area in tune-space, while the TME and 72° FODO lattice are comparable. The biggest difference is in the detuning with amplitude: while the TME lattice shows a strong detuning of horizontal tune with horizontal amplitude, while both FODO lattices have a dominant cross term. The values of the detuning terms are summarized in Table 1.

Table 1: Summary of tunes, chromaticities, first-order detuning terms and sextupole strength.

	90° FODO	TME	72° FODO
Q_x	54.87	54.87	35.87
Q_y	45.80	19.80	32.80
ξ_x	-87	-112	-42
ξ_y	-66	-41	-44
$\partial Q_x / \partial J_x$	-1.9×10^{-3}	-31.7×10^{-3}	-0.7×10^{-3}
$\partial Q_y / \partial J_y$	-11.7×10^{-3}	0.8×10^{-3}	-3.4×10^{-3}
$\partial Q_x / \partial J_y$	7.4×10^{-3}	-4.1×10^{-3}	1.1×10^{-3}
$\partial^2 Q_x / \delta^2$	265	607	100
$\partial^2 Q_y / \delta^2$	-10.1	-1.5	16
SF [m^{-2}]	2.38	1.27	0.68
SD [m^{-2}]	1.51	1.07	0.39

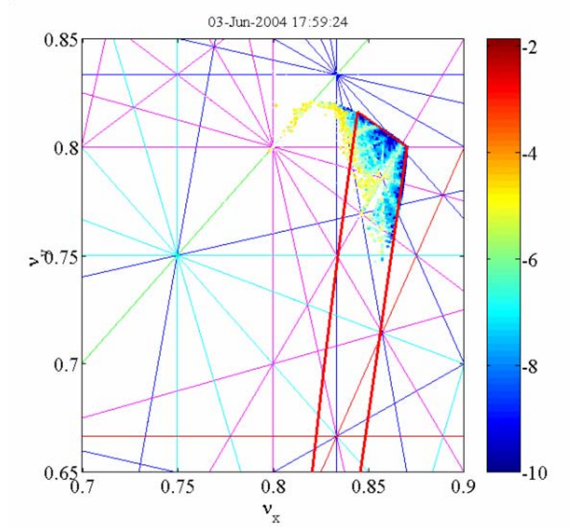

Figure 4: Frequency map of short 90° FODO lattice.

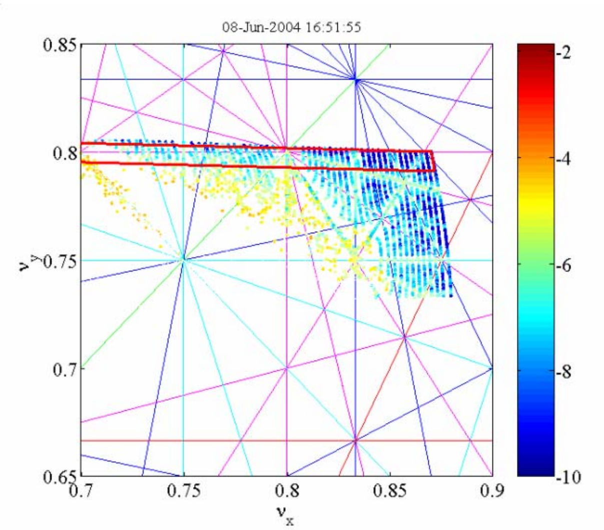

Figure 5: Frequency map of TME lattice.

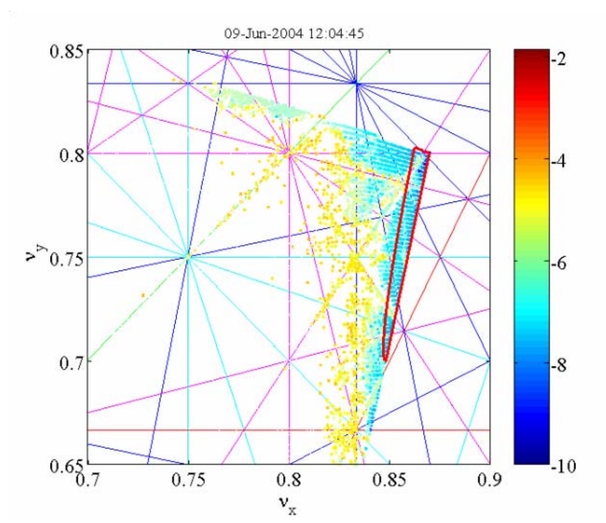

Figure 6: Frequency map of 72° FODO lattice and damping wigglers. Thick red line encompasses the area in tune space corresponding to the physical aperture.

Injection Efficiency

The injected emittance is of the order of 350 nm rad. To reach safely an injection efficiency of close to 100 %, an acceptance of 30mmmrad is needed. The geometric aperture is limited by the insertion device gaps to 2.2 mm mrad in the vertical plane and to 30 mm mrad in the horizontal plane. During injection the beam will fill almost the entire aperture. Correspondingly a certain area in tune space is occupied, as marked in Figure 4 to Figure 6. It can be seen that the large detuning terms of the TME and 90° FODO lattice together with strong resonances will lead to a limitation of the achievable dynamic aperture. Even for the 72° FODO injected particles will cross some resonance areas during damping.

Stability of the particles for one damping time has thus been checked again with tracking calculations. Figure 7 shows the border of stable motion in amplitude space for particles being tracked for 8192 turns in the lattices without wigglers and 2048 turns in the lattice with wiggler. This corresponds approximately to one damping time.

As expected only the 72° FODO lattice with damping wigglers provides a dynamic aperture that is comparable to the physical aperture. The observed resonance areas (see Figure 6) will not lead to beam loss within one damping time.

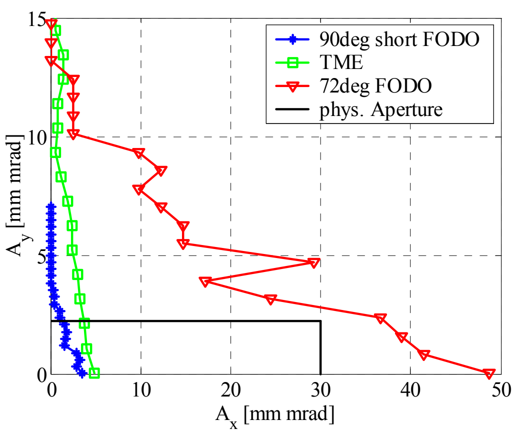

Figure 7: Comparison of dynamic apertures for the different lattice types 72° FODO, TME, and 90° short FODO.

Momentum Aperture

Beam lifetime is dominated by inelastic scattering of particles within the bunches (Touschek-Effect). The lifetime is proportional to the third power of the momentum acceptance of the ring, which in turn is given by the installed RF power and the off-momentum dynamic aperture. Tracking calculations for various momentum offsets and horizontal amplitudes have been performed, with the vertical amplitude being scaled according to a 1 % emittance coupling. After a momentum change due to inelastic scattering particles will perform betatron oscillations around their dispersion orbits. The amplitude of these oscillations varies depending on where the scattering occurs and is largest at places with a large dispersion function. Figure 8 shows the results of the tracking together with lines displaying the betatron oscillation amplitude of a Touschek scattered particle at the high dispersion sections in the various rings. The off-momentum aperture for scattering at these positions is given by the intersection of the two lines. It varies between 1.0% for the TME lattice and 1.3% for the 72° FODO lattice. It is interesting to note that the Touschek lifetime is almost comparable for the various lattice types, because the reduction in momentum aperture goes in hand with a reduction of the amplitude excitation function.

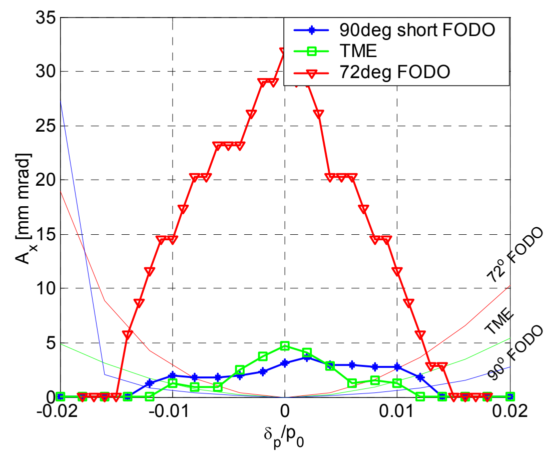

Figure 8: Off-momentum apertures for the different lattice types 72° FODO, TME, and 90° short FODO. Tracking has been performed with an aperture limitation corresponding to the real physical aperture of approx. 30 mm mrad.

SUMMARY

Three different lattice options have been developed for PETRA III. Their non-linear properties are investigated with the help of tracking calculations Only the 72° FODO lattice together with damping wigglers has a large enough on- and off-momentum dynamic aperture and will thus provide sufficient injection efficiency and Touschek lifetime.

REFERENCES

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