LOW EMITTANCE OPTICS FOR PETRA II

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Abstract

Due to the large bending radius, the strong quadrupoles and the large number of sextupoles in the electron positron storage ring PETRA at DESY it is possible to realize electron optics with extremely small emittance. Using the PETRA II lattice configuration, as it will be realized in the electron and proton booster version for HERA, it is shown that $\varepsilon_x/E^2 = 4.92 \times 10^{-11}$ m·rad/GeV^2 (E_{max} = 5 GeV) and $\varepsilon_x/E^2 = 9.96 \times 10^{-11}$ m·rad/GeV^2 (E_{max} = 15 GeV) are feasible without any additional damping device.

Tracking calculations have been performed to show that chromaticity compensation by sextupoles leaves sufficient nonlinear acceptance.

Introduction

The electron-positron storage ring PETRA at DESY will be used as the electron (14 GeV) and proton (40 GeV) injector for HERA ("PETRA II", see ref. [1]). Nevertheless it might be interesting to know the limits of low emittance operation with PETRA II.

During its past e^+/e^--luminosity era, the optics has been designed to yield optimum emittance values for maximum luminosity. Except for maximum energy operation (above 22 GeV), the optimum emittance value was usually considerably larger than the minimum possible one.

Low emittance optics for PETRA

To yield small emittance in PETRA, one needs strong focussing in the arcs to minimize $\mathcal{H} = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x D_x'^2$ (α,β,γ = Twiss parameters, D and D': dispersion function and its derivative) in the bending dipoles. Then, due to the small dispersion value, large sextupole strengths are required to compensate for the linear chromaticity of the ring, resulting in dynamic aperture limitations, see section 2 of this paper. It is an advantage of the PETRA II version in this respect, that the linear chromaticity contribution of the straight sections is drastically reduced, because the low beta inserts are omitted. When considering the PETRA II electron lattice remember that it consists of four identical quadrants, each of them mirror symmetric with respect to the center of a straight section. Therefore one octant reflects all lattice and optics properties of the whole ring (except a slightly asymmetric sextupole distribution, see section 2).

Due to the long periodic lattice in the PETRA arcs, sophisticated low emittance optics are excluded as long as the lattice is not changed. However, the large bending radius (192 m) and the large number of sextupole magnets (there is a sextupole magnet at each quadrupole in the arcs) help a lot.

Three different optics have been investigated. At first sight the maximum energy for all of these optics is given by sextupole saturation, but it is questionable if the dynamic aperture accomodates enough standard deviations of the natural beam size at highest energies (recall that the electron emittance scales with the beam energy squared).

In all low emittance optics the dispersion D_x is suppressed in the straight sections and, in addition, small beta values are realized in that part of the straight sections where cavities are installed (suppression of instabilities and synchro-betatron resonances).

Maximum energy 5 GeV: With phase advances φ_x = 148°, φ_z = 76° per FODO cell a horizontal emittance of $\varepsilon_x/E^2 = 4.92 \times 10^{-11}$ m·rad/GeV^2 can be realized up to E_{max} = 5 GeV. The optic is nearly periodic in the arc. Since three of four long straight sections are not used for cavities any more, one might think of additional damping wigglers in the free long straight sections. With 3 x 12 wigglers (10 periods of 0.4 m each, B ≈ 0.9 T), a further reduction of the horizontal emittance by a factor of 3 might be possible without severe optics distortions. Tolerance and orbit distortion studies have not been undertaken yet.

Maximum energy 7 GeV: With phase advances φ_x = 109° and φ_z = 55° per FODO cell the horizontal emittance is $\varepsilon_x/E^2 = 6.44 \times 10^{-11}$ m·rad/GeV^2. The optics functions are displayed in fig. 1 for one PETRA octant. Although we favour a maximum operation energy of 7 GeV for this optics to have some room for optimization, the sextupole saturation allows up to 9.5 GeV. Fig. 2 shows that the nonlinear chromaticity is moderate.

Maximum energy 15 GeV: With phase advances φ_x = 86°, φ_z = 48° per FODO cell the resulting horizontal emittance is $\varepsilon_x/E^2 = 9.96 \times 10^{-11}$ m·rad/GeV^2. Tunes are Q_x = 38.43, Q_z = 27.13, the linear chromaticity is only ξ_x = - 46, ξ_z = - 40.

Dynamic Aperture

Due to the very strong focussing in the arcs and the corresponding small dispersion function, the sextupoles necessary for chromaticity compensation have to be very strong. This introduces strong nonlinearities and a severe reduction of the acceptance is expected. The situation further worsened by the fact that, while the linear lattice of PETRA has 4-fold symmetry, the sextupole distribution has not because at some places sextupoles have to be removed to allow for the installation of proton injection and ejection kickers.

We have done first studies of the dynamic aperture for both the 5 GeV and the 7 GeV optics with a 2-family sextupole distribution using the particle tracking code RACETRACK [2]. An ensemble of 4 particles was tracked over 1500 revolutions. Imperfections and synchrotron oscillations were not taken into account in this first investigation. The resulting dynamic aperture is shown in fig. 3. It appears to be safely large enough to accomodate the stored beam, but especially for the 5 GeV optics injection and accumulation would be a severe problem due to the small horizontal acceptance.

Preliminary studies have shown that the dynamic aperture could be increased by about a factor of 2 if the 4-fold symmetry is approximately restored by

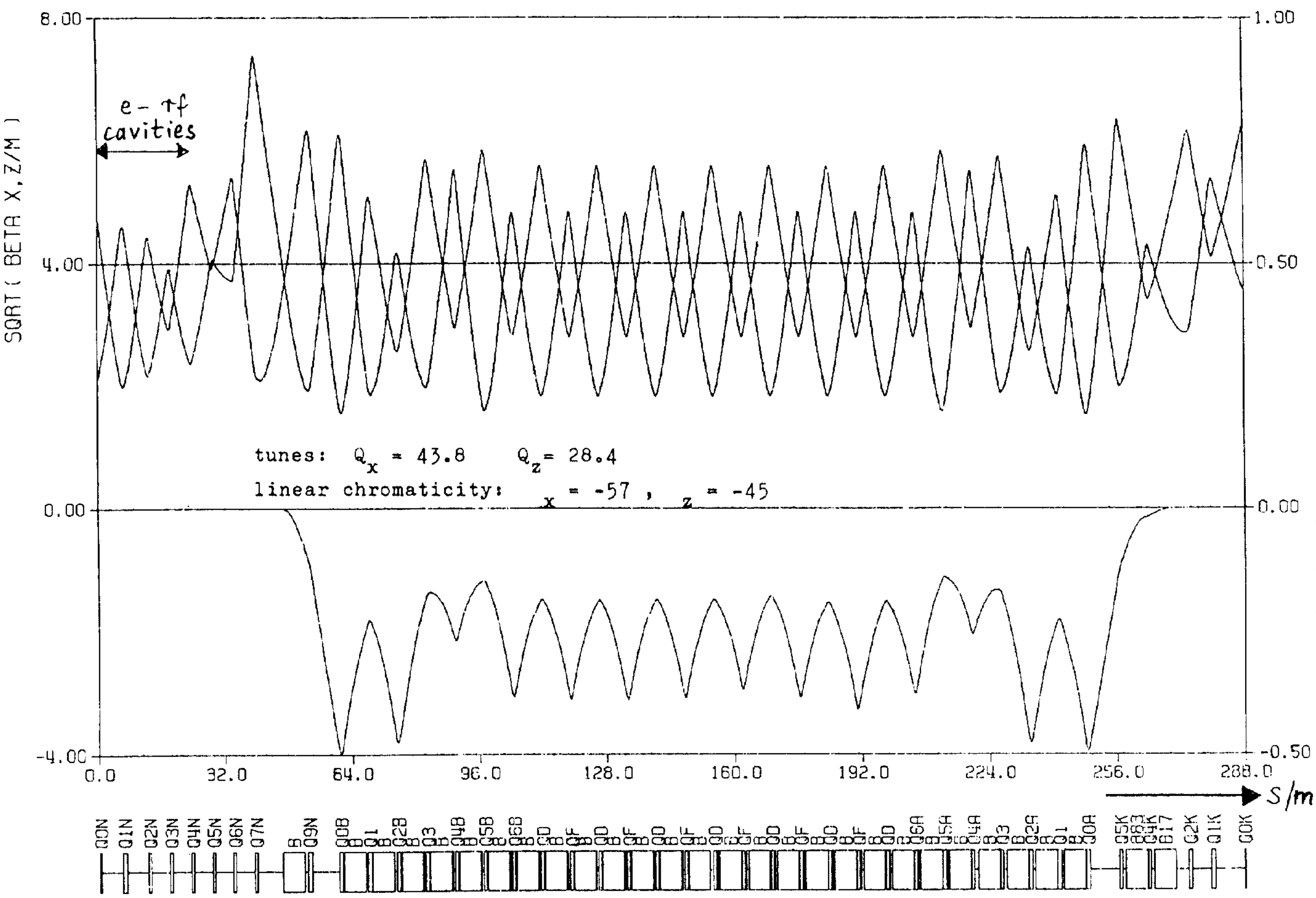

Figure 1: Low emittance electron optics in the PETRA II octant, maximum energy 7 GeV

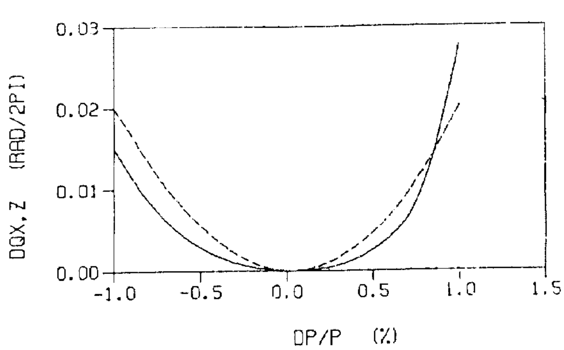

Figure 2: Energy dependence of tunes (i.e.chromaticity) of the 7 GeV low emittance optics

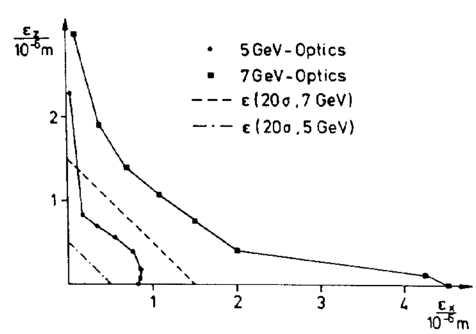

Figure 3: Dynamic aperture of the 5 GeV and 7 GeV optics obtained from tracking calculations.

introducing additional sextupole families in the straight sections.

References

[1] J. Rossbach, PETRA II: Electron optics, Proton Optics and Tracking Studies for the e/p Injector for HERA, this conference.

[2] A. Wrulich: RACETRACK - A Computer Code for the Simulation of Nonlinear Particle Motion in Accelerators, DESY 84-026, 1984.