DYNAMIC APERTURE STUDIES FOR PETRA III INCLUDING MAGNET IMPERFECTIONS

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Abstract

PETRA III is a 3rd generation synchrotron radiation light source. Efficient injection in the top up mode requires a dynamic aperture of 30 mm mrad or larger, while a 2 hour Touschek lifetime needs an average momentum aperture of around 1.5 %. We present studies on the impact of recently measured magnet imperfections on the available dynamic aperture. To this end, tracking simulations have been performed including the effects of measured multipole errors of lattice magnets and of 20 four-meters-long damping wigglers.

INTRODUCTION

The PETRA storage ring is currently rebuilt as a dedicated 3rd generation light source providing high brilliance synchrotron radiation for the users [1]. This machine, called PETRA III (main parameters are listed in table 1), consists of seven octants with a 72° FODO lattice, while the 8th octant is redesigned featuring 9 double bend achromat (DBA) cells with dispersion free straight sections for the installation of up to 14 undulators. Eight of the nine cells provide space for either two 2 m long or one 5 m long undulators while the ninth cell will accommodate a 10 m long undulator. The arcs of the eight octants are connected by short and long straight sections in alternation. The emittance of the bare machine (without insertion devices) is 4.2 nm rad. Two of the long straight sections, one in the west and one in the north, will accommodate in total 20 damping wigglers needed to achieve the design emittance of 1 nm-rad. PETRA III is foreseen to operate in two modes, a 960

Table 1: Main parameters of PETRA III.

Energy [GeV]	6.0
Circumference [m]	2303.952
Current [mA]	100
Emittance Hor./Ver. [nmrad]	1.0/0.1
Number of Bunches	960/40
Harmonic Number	3840

and a 40 bunch mode, both with a beam current of 100 mA. Thus, the 40 bunch mode requires single bunch intensities of 2.5 mA conspiring with the small emittance to yield a Touschek lifetime as small as 2 hours. Beam stability in turn requires to operate in a top up mode.

Efficient injection in the top up mode requires a dynamic aperture of 30 mm mrad while a 2 hour Touschek lifetime needs an average momentum aperture of around 1.5%. In previous studies the linear and nonlinear beam dynamics

effects of the lattice including chromaticity correction as well as the influence of the wigglers and undulators have been scrutinized [2, 3, 4]. The small bending angle of 2.5° in the DBA section leads to small values for the dispersion function. A careful investigation of possible sextupole configurations shows that a local correction of the chromaticity should be abandoned in favor of a global compensation using the sextupoles in the FODO octants [3].

We extend the dynamic aperture studies by including the results of the recently measured field quality of the refurbished lattice magnets as well as the multipole errors of the damping wigglers. For this purpose extensive tracking studies have been performed using an extended version of the SIXTRACK code [5].

MACHINE MODEL

The baseline model of the machine consists of the chromaticity corrected machine including all insertion devices as summarized in table 2. Linear optics calculation and extraction of global ring properties is performed using MAD-X [6] where the the insertion devices are treated either as linear transport matrices derived from field fitting for optics matching or using a hard edge dipole model for the calculation of radiation properties. This baseline model is supple-

Table 2: Listing of the insertion devices included in the model of PETRA III.

	Number of Devices	Unit length [m]	Period length [mm]	Peak field [T]
Wigglers	20	4	200	1.55
Undulators	10	2	27.8	0.84
	3	5	27.8	0.84
	1	10	27.8	0.84

mented to include multipole errors obtained from magnet measurements. Multipole coefficients have been measured for all magnets. The coefficients for the dipoles are taken from the analysis in [7]. For the new dipoles no data were available. We assume the same values as for the old dipoles normalized to the deflection angle of 44 mrad. More recently, the field quality of the quadrupoles to be used in the FODO octants has been measured after their refurbishment with new coils. A distribution of multipole coefficients has been extracted from around 70 data sets for the two quadrupole types (short and long) in use. The resulting relative sextupole and octupole components are summarized in table 3. Data for 76 short and 18 long quadrupoles to be installed in the DBA octant have been used to calculate

Table 3: Relative sextupole and octupole coefficients for refurbished PETRA III quadrupoles installed in the FODO octants.

Quadrupoles FODO Octant			
short ($\delta_0 = 4.25$mrad)		long ($\delta_0 = 4.0$mrad)	
normal	skew	normal	skew
1×10^{-4} ($r_0 = 25$ mm)			
3	0.0±1.38	-0.28±2.0	0.20±0.87	-0.8±1.77
4	1.72±2.14	-0.47±0.6	0.36±1.05	0.0±0.41

a distribution of their multipole coefficients. The resulting relative sextupole and octupole components are collected in table 4. In order to simplify the input of the tracking

Table 4: Relative sextupole and octupole coefficients for PETRA III quadrupoles installed in the DBA octant.

Quadrupoles DBA Octant			
short ($\delta_0 = 6.5$mrad)		long ($\delta_0 = 9.5$mrad)	
normal	skew	normal	skew
1×10^{-4} ($r_0 = 25$ mm)			
3	-0.84±1.59	-0.78±1.77	-0.4±0.83	-0.9±1.86
4	-0.45±1.05	0.0±0.41	0.08±0.97	-0.1±0.28

simulations the multipole errors have been normalized to the maximum deflection angle at the reference radius r_0 of the specific quadrupole type occurring in the machine. This overestimates the multipole errors and should be viewed as a conservative approximation. As can be seen in table 3 and 4 the dominant multipole contributions are skew sextupoles and normal octupoles.

The first and second field integral of the damping wigglers have been measured using a stretched wire setup after correctors for the residual vertical and horizontal field integral have been installed to match the required field quality specifications in a good field region of approximately ±30 mm. Ideally one would integrate the fields along a sinusoidal trajectory in the device but integrating along a straight line should be a sufficient approximation. Figure 1 shows the results of the horizontal and vertical first field integral measurement for two out of the twenty damping wigglers together with sixth order fits to the data. The multipole coefficients used for the model are extracted from these fits.

TRACKING STUDIES

Tracking studies for PETRA III are performed using an extended version of the SIXTRACK code apt to handle insertion devices with several methods [8]. It allows for a 6-dimensional symplectic tracking and includes an internal post-processing of the tracking data for e.g. frequency map analysis.

The undulators foreseen for PETRA III are modeled using an analytical generating function method. Their short period length allows to reduce the model to the fundamental mode. The damping wigglers are described using a fourth order numerical generating function [2]. The multipole error distributions are added to this model. Realis-
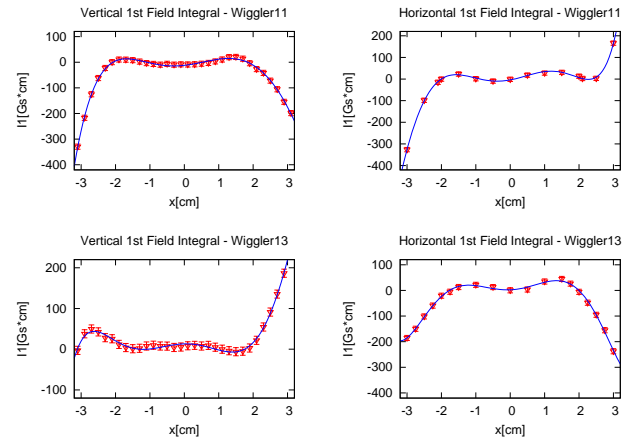
Figure 1: Field measurements for two out of twenty damping wigglers with sixth order fits to the data.

tic tracking simulations have to take into account the strict physical aperture limits put by the small vertical gap in the undulator section. These limits are present in our simulations. No random optics errors or misalignments are considered. Based on the model described above tune space
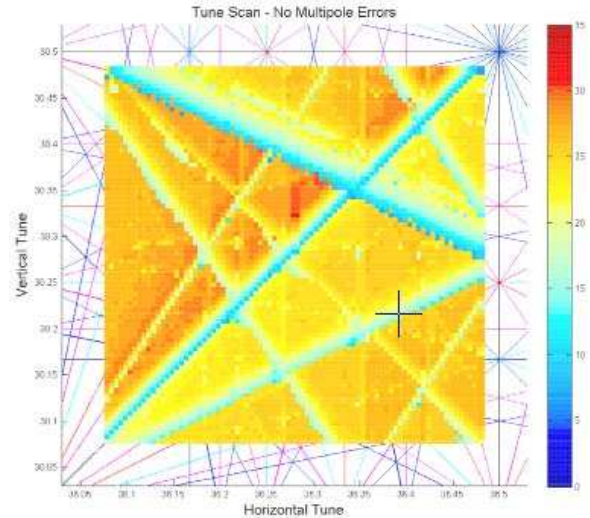

Figure 2: Tune scan for the baseline model including all insertion devices. The color code labels the available dynamic aperture in mm mrad.

scans have been performed to visualize the dynamical aperture in the presence of lattice magnet errors and the multipole components of different damping wigglers. For each point in an 81×81 tune grid the dynamic aperture is found by increasing the horizontal amplitude until the particle is lost. The vertical amplitude is increased simultaneously with a fixed ratio of 5%. Figure 2 shows a tune scan of the baseline model without any multipole errors. This has to be compared with the model including magnet imperfections as is depicted in figure 3 where wiggler 11 has been chosen representatively. The excitation of many resonances is clearly visible in this plot, most prominently the skew sextupole driven $3Q_y$ and $2Q_x\pm Q_y$ resonances and the skew octupole resonance $3Q_x$-Q_y. In absence of multipole errors the region below the line Q_x+2Q_y in the tune diagram
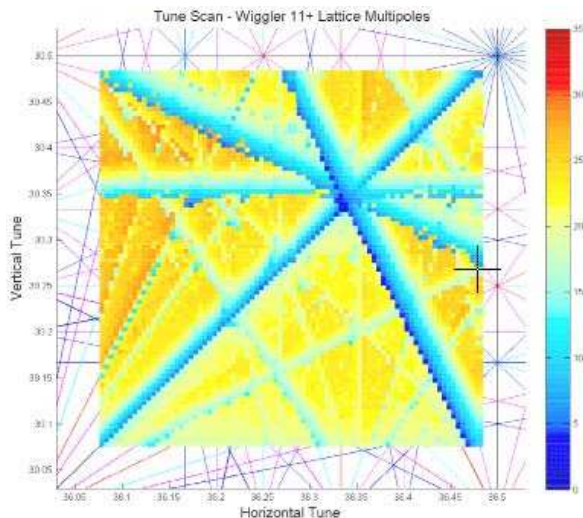
Figure 3: Tune scan including the multiples of wiggler 11 and lattice multipole contributions. The color coded dynamical aperture is reduced but still reaches well above 25 mm mrad in the region of the nominal tune Q_x=36.115/Q_y=30.32.

exhibits large dynamic aperture. This is substantially reduced by the resonance node at Q_x=Q_y=1/3. However, this region is also disfavored by momentum acceptance considerations where strong synchro-betatron satellites reduce the available off momentum dynamic aperture.

Currently, the working point is chosen as Q_x=36.115 and Q_y=30.32. This region is only weakly affected by the multipole errors considered so far, although the excitation of the $3Q_x$-Q_y resonance line slightly reduces the available area in tune space. Figure 4 compares the on momentum dynamic aperture for different multipole error configurations. The main reduction of the dynamic aperture already occurs when the lattice magnet imperfections are added while the contribution of the wiggler multiples has smaller impact. Depending on the detuning with amplitude the situation might even slightly improve. Figure 5 compares
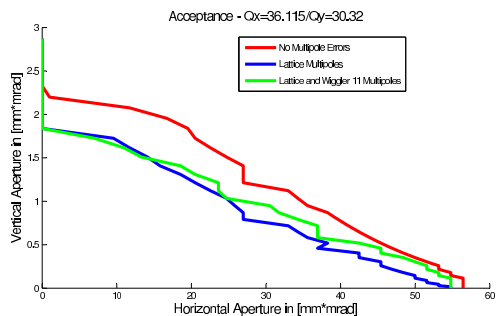

Figure 4: Comparison of the on momentum dynamic aperture for different multipole configurations at the working points Q_x=36.115/Q_x=30.32 .

the available dynamic acceptance as a function of the initial momentum offset for the baseline model and the model including multipole errors. At a fixed initial momentum offset the vertical amplitude was increased together with the horizontal by a ratio of 1% until the particle is lost. For this choice of working point the influence of the mul-

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tipole errors on the momentum acceptance is weak. The momentum acceptance exceeds the necessary 1.5% also in the presence of multipole errors and is sufficient for injection even at a $\delta p/p$ of 1%.
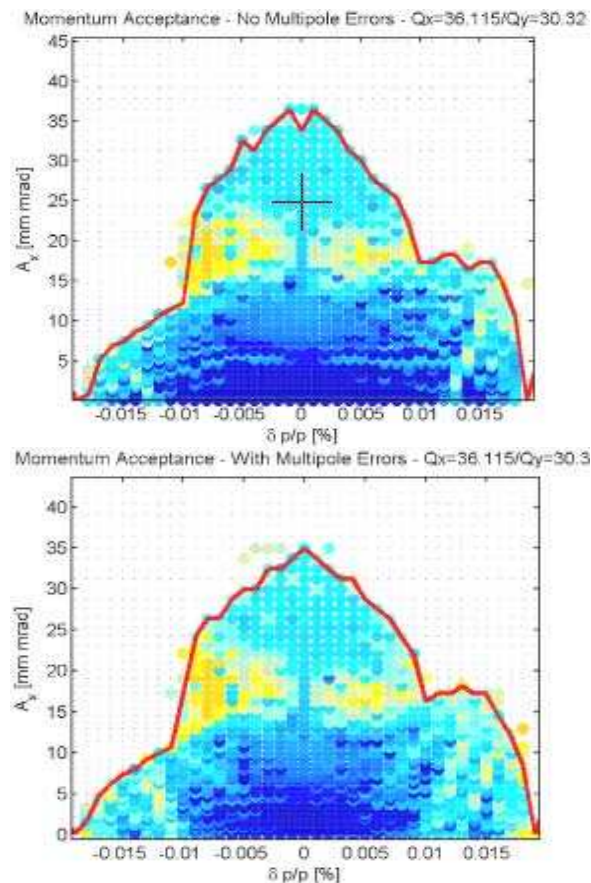

Figure 5: Comparison of the momentum acceptance for the baseline model and the model including multipole errors of lattice magnets and wiggler 11. The acceptance is sufficient for injection even at a $\delta p/p$ of 1 percent.

ACKNOWLEDGMENTS

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