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MULTI-OBJECTIVES GENETIC ALGORITHMS (MOGA) OPTIMIZATION OF PETRA IV SCENARIOS

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Abstract

Multi-Objectives Genetic Algorithms (MOGA) are applied to optimize the dynamic properties of the PETRA IV reference lattice to convert PETRA III storage ring into an ultra-low emittance hard X-ray radiation source. The lattice used is based on an ESRF-like multi bend achromat lattice with a natural emittance of 15 pm mrad. According to the simulations, the Touschek lifetime is improved by a factor 2 and the dynamic aperture is enlarged by 2 mm respect to the inital value of the reference lattice of PETRA IV.

INTRODUCTION

In last years, a new generation of ultra-low emittance rings is emerging to upgrade the performance of the actual 3rd generation of synchrotron light sources. DESY has also iniatiated an upgrade of PETRA III to convert the storage ring in a diffracted limited one: PETRA IV.

PETRA IV will be allocated at the PETRA III tunnel, which consists on eight arcs of 201.8 m connected by four short and four long straight sections of 64.8 m and 108 m long, respectively (Fig. 1). The injection point will be in the South straight section with a horizontal betatron function of 100 m to enlarge the dynamic aperture during injection. In addition to the existing halls, it is planned to built an additional hall to increase the existing 24 beam lines allocated in the North, von Laue and East Halls. The parameters of PETRA IV design are shown at Table 1.

Table 1: PETRA IV Design Parameters

Parameter	Value	Range
Energy [GeV]	6	(4.5 . . . 6)
Circumference [m]	2304	
Current [mA]	200	(100 . . . 200)
Number of bunches	~ 1000	
Emittance hor. [pm mrad]	10	(10 . . . 30)
ver. [pm mrad]	5	(10 . . . 30)
Bunch length [ps]	~ 100	
Harmonic number	3840	

As result of these studies, one lattice design based on an ESRF-like hybrid multi bend achromat (HMBA) approach [1] emerges as a candiate for PETRA IV [2]. The basic reference lattice cell consists in an hybrid seven bend achromat (H7BA) cell of 25.2 m long with 5 m free space for the IDs and 6.6 m and 2.1 m of horizontal and vertical beta function, respectively. The chromatic sextupoles are allocated in dispersion bumps of 4.3 cm for chromaticity correction and with a phase advance condition of 3π and π

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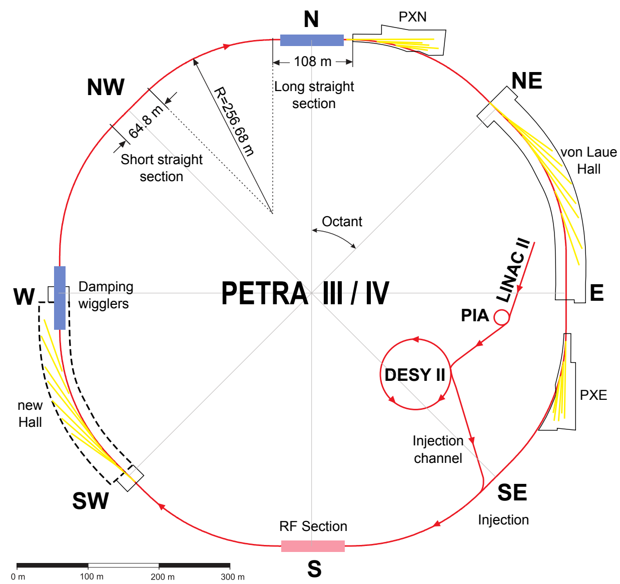

Figure 1: Layout of PETRA III-IV with location of damping wigglers (DW) and existing halls with beam lines.

in the horizontal and vertical planes, respectively to cancel high orders sextupole aberrations. Altought the strenghts of quadrupoles remains in a reasonable level (less than 90 T/m), the sextupoles are 2.4 times stronger than the sextupoles used at ESRF. A new cell of 26.2 m long is under investigation to relax the sextupole strenghts.

Many iterations have been done to optimize the reference lattice of PETRA IV [2]. The reference lattice used during simulations is a preliminar version designed at summer of 2017.

GENETIC ALGORITHMS

Multi-Objective Genetic Algorithms (MOGA) [3] has become a basic tool for optimization of new ultra-low emittance storage rings due to its successful implementation over the last years. The progress in the performance and costs of farms of CPUs dedicated for high level computation has made GA very attractive to the synchrotron light sources community. GA complements the existing analytical methods to optimize the beam dynamics of such facilites due to its capability to systematically explore the multi-parameter space determined by hundred of magnets. GA are efficient once the lattice has been already optimized and presents reasonable dynamic properties.

Due to the typically strong focusing of the ultra-low emittance rings to enlarge the brilliance, the aberrations introduced by the sextupoles to correct the natural chromaticites becomes extremely relevant giving rise as consequent a dramatically reduction of the dynamic properties: the on-

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momentum dynamic acceptance (DA) of such machines are typically insufficent for off-injection schemes and the momentum acceptance (MA) is also diminished producing small values of beam lifetime. Particularly for PETRA IV, it is needed a dynamic aperture of 10 σ for the stored beam plus 4 σ for the injected beam plus 3 mm for the septum blade, then a total required dynamic aperture of 7 mm or a dynamic acceptance of 0.5 mm mrad. Actually, the dynamic aperture of the reference lattice is 11 mm, but it will be dramatically reduced (typically a factor 2) introducing alignments and field errors and it will not fit the requirements. Therefore, the objective of this study is to see whether it is possible to enlarge the dynamic properties preventing the effect of alignmet and field errors.

The type of MOGA used in this study was developed at APS, it is based on NSGA-II algorithm [4] and it uses Elegant [5] as tracking code.

SIMULATIONS

The model used during simulations includes two families of quadrupoles to vary the fractional part of the global tune in a range between 0.1 and 0.4 to avoid indesirable effects of integer and half-integer resonaces, four chromatic and two harmonic sextupoles families and two families of octupoles. The model considered is ideal: it does not include the dimensions of the vacuum chamber, errors and undulators.

Both dynamic and momentum apertures are tracked including the synchrotron oscillation, 6 MV of RF voltage and 500 MHz of RF frequency. The Touschek lifetime is computed considering 2.1 mm of bunch length at zero current, 200 mA of total current and 10 % of coupling. A timing mode of 80 bunches is selected to enlarge the contribution of the Touschek lifetime instead the gas lifetime.

Because of tracking, a list of approximations are assumed to speed up the process:

- The total summatory of the Resonance Driving Terms (RDT) is included as optimization objective. As it is shown in reference [6], small values of RDT are necessary but not a suficient condition for large values of DA.
- The number of turns considered for tracking is 100. However the results of the Pareto front are refined with 1000 turns to check their completness.
- The tracking of the local momentum aperture (LMA) is done at the location of the quadrupoles of the first 16th part of the total machine. The total LMA is reconstructed from this previous results. This approximation underestimates the contribution of the LMA in the computation of the Touschek lifetime because it does not take into account the LMA of the straight sections.

Figure 2 shows the solutions obtained by MOGA for the dynamic properties of the PETRA IV reference lattice tracking the particles in the middle of the South-West short straight section with an horizotnal beta function of 11.9 m. The Touschek lifetime is improved almost a factor 3 and the area of the DA is increased 25 %. A population of circa 6.500 individuals were obtained after 5 days of computation using 300 CPUs of the BIRD cluster [8]. The red point indicates the dynamic properties of the PETRA IV reference lattice and the Pareto front is despicted using blue dots. Two solutions of the Pareto front are selected to check their completeness: solution #112 (magenta dot) with improved DA and solution #1453 (green dot) with improved Touschek lifetime.

Figure 3 shows the tune scan region explored by MOGA using a color-code proportional to the Touschek lifetime. The solutions with larger Touschek lifetime are concentrated for vertical tunes near to 67.37. The solutions remain confined into the tune range imposed as expected.

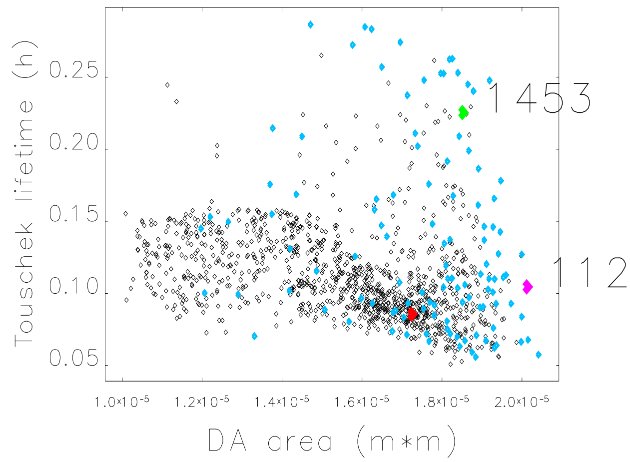

Figure 2: Optimization of PETRAIV reference lattice obtained by MOGA in the South-West straight section.

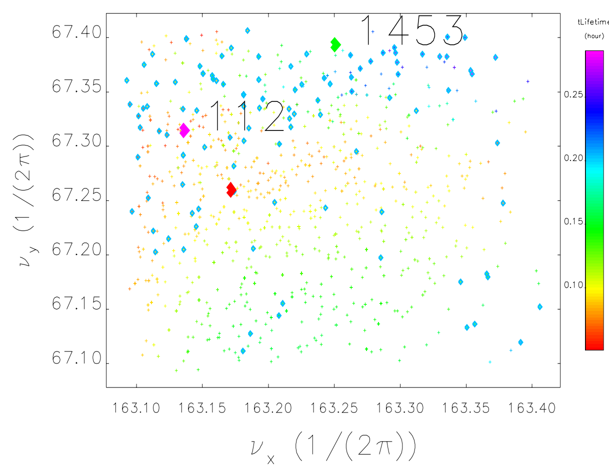

Figure 3: Tune region explored by MOGA color-coded with the values of Touschek lifetime.

Table 2 shows the values of Touschek lifetime and area of the DA of the selected optimized solutions of the Pareto front computed at the injection point with an horizontal beta function of 100 m and taking into accout 1000 turns. The negative side of the DA is enlarged 2 mm respect to the initial 11 mm of the reference lattice improving in turn the dynamic acceptance from 1.3 mm mrad to 2 mm mrad (Fig. 4). The

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Table 2: Area of the DA and Touschek Lifetime of the Optimized Solutions with 1000 Turns

Solution	DA Area (mm^2)	T. Lifetime (h)
Reference lattice	15.4	0.08
#112	16.2	0.09
#1453	18.1	0.19

Touschek lifetime is increased by a factor of 2 due to the improvement of the LMA shown in Fig. 5.

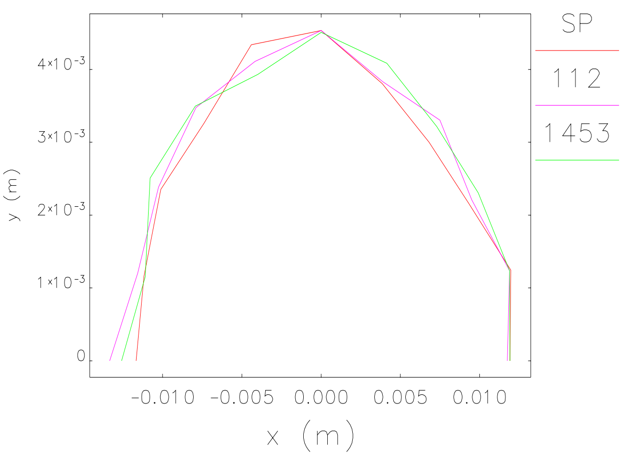

Figure 4: DA of the reference lattice of PETRA IV and two selected solutions.

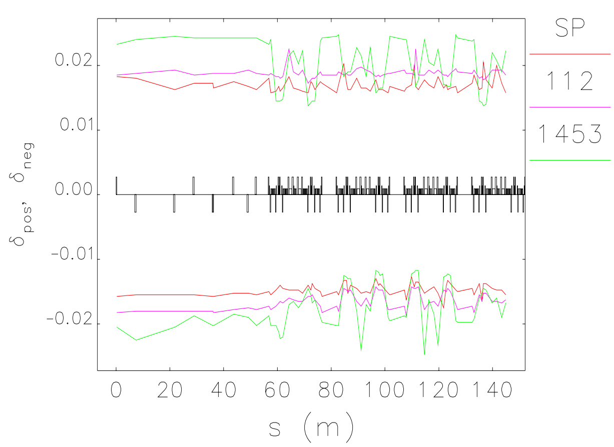

Figure 5: MA of the reference lattice of PETRA IV and two selected solutions.

CONCLUSION

MOGA has been applied to optimize the dynamic properties of a preliminar version of the PETRA IV reference lattice. The dynamic acceptance has been increased 20 % and the Touschek lifetime is 2 times larger than the dynamic properties of the reference lattice. Altought there is a significant improvement of the dynamic acceptance, it is not sufficient to fit the requirements of the current off-injection scheme preventing the introduction of aligment and field errors. In this sense, a longer cell of 26.2 m is under investigation to relax the magnet strengths and to fit the requeriments of the off-axis injection scheme.

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