MULTI-OBJECTIVE ONLINE OPTIMIZATION OF BEAM LIFETIME AT APS*

Yipeng Sun†, ANL, Argonne, IL 60439, USA

Abstract

In this paper, online optimization of beam lifetime at the APS (Advanced Photon Source) storage ring is presented. A general genetic algorithm (GA) is developed and employed for some online optimizations in the APS storage ring. Sextupole magnets in 40 sectors of the APS storage ring are employed as variables for the online nonlinear beam dynamics optimization. The algorithm employs several optimization objectives and is designed to run with topup mode or beam current decay mode. Up to 50% improvement of beam lifetime is demonstrated, without affecting the transverse beam sizes and other relevant parameters. In some cases, the top-up injection efficiency is also improved.

OVERVIEW

Multi objective optimization methods and techniques are widely used [1] (see a review in [1]) in many aspects of engineering and physics studies, including the genetic algorithms [2, 3]. Starting in 2005 [4, 5], accelerator and beam applications became widespread. For storage rings, the dynamic acceptance, local momentum acceptance and Touschek lifetime, and other nonlinear terms were optimized using genetic algorithms in tracking simulations [6–10].

Online machine-based single- or multi-objective optimizations were also performed on operating storage rings [11,12]. For example, beam loss rate was employed to minimize average vertical beam sizes in SPEAR3 ring by applying the genetic algorithms [11]. Dynamic apertures of the SPEAR3 ring was optimized by tuning sextupole magnets with online optimizations [12]. Here online optimization of beam lifetime at the APS (Advanced Photon Source) storage ring is presented, which is similar to the study of Huang [12]. The online machine-based optimizations of nonlinear beam dynamics may have an advantage over nominal simulation-based techniques, as it is applied with the accelerator models replaced by the real accelerators.

The Advanced Photon Source storage ring is a third-generation synchrotron radiation light source, with a circumference of 1104 meters [13], 40 sectors and an effective beam emittance of 3.13 nm [14]. The main operational lattice has reduced horizontal beam size (RHB) at one ID straight. The linear optics in one of the 38 nominal sectors is shown in Fig. 1, where the starting and ending point are the insertion device (ID) center. In the following sections, some experimental results of lifetime optimization are presented and discussed. The nominal bunch fill pattern is 24 equi-spaced bunches, with a total beam current up to 102 mA.

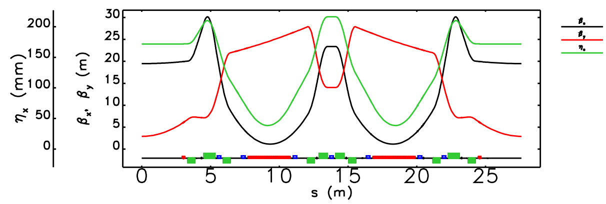

Figure 1: Twiss parameters in one arc section of APS storage ring. Green blocks represent quadrupoles, red blocks represent dipoles, and blue blocks represent sextupoles.

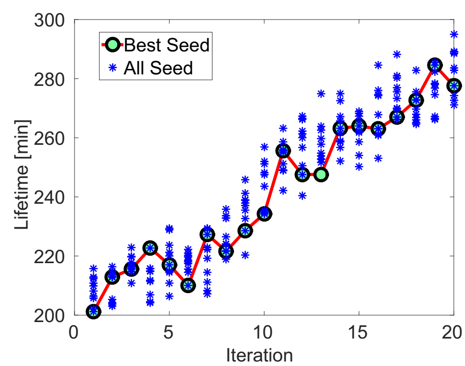

Figure 2: Lifetime (calculated using DCCT current measurements) at each iteration. A total of 20 iterations (finished in a short time), and 10 seeds for each iteration. Starting point is optimized sextupoles from MOGA simulation [7] [15] on the high chromaticity lattice (ξ = 11).

OPTIMIZATION ALGORITHM

A genetic algorithm was developed and employed for some online optimizations in APS storage ring. Compared with nonlinear beam dynamic optimization through numerical tracking simulations, online machine-based optimization targets the measured, rather than predicted, real accelerator performances. Possible optimization objectives include the beam lifetime, injection efficiency, beam loss [11], and transverse beam sizes measured at the pinhole camera. The optimization variables may include the quadrupole magnet strengths, skew quadrupole magnet strengths, sextupole magnet strengths [12], and upstream injectors.

For the lifetime optimization, sextupole magnets in up to 40 sectors of the APS storage ring were employed as tuning knobs. There are seven sextupole magnets in each sector which are usually powered as seven families for more

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† yisun@aps.anl.gov

degrees of freedom. In sector 4 and sector 5, the sextupole magnets are sometimes tuned independently for optimized beam phase space [16] to accomodate the narrow physical aperture at ID4. Orbit feedback is always running to maintain a similar closed orbit.

The optimization algorithm has the following features.

- Work with top-up or beam current decay mode
- Improve lifetime and/or injection efficiency by tuning sextupoles
- Constrain other parameters (beam sizes etc.) simultaneously

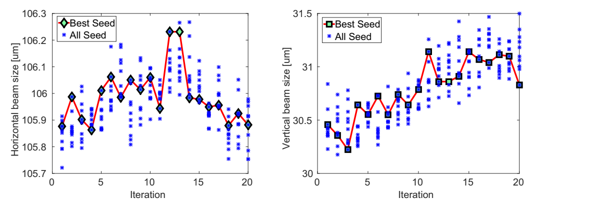

Figure 3: Horizontal and vertical beam size (at sector 35 pinhole location) for each iteration. A total of 20 iterations, and 10 seeds for each iteration. Starting point is optimized sextupoles from MOGA simulation [7, 15] on the high chromaticity lattice ($\xi = 11$).

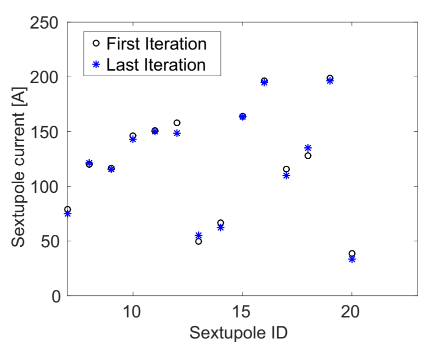

Figure 4: Sector 4 and 5 sextupole magnets strength for the first and last iteration (a total of 14 sextupoles). Starting point is optimized sextupoles from MOGA simulation [7,15] on the high chromaticity lattice ($\xi = 11$).

BEAM CURRENT DECAY MODE

For the beam current decay mode, the optimization objective employed by COGA (Combined Objective Genetic Algorithm) is a combined function of beam lifetime, total beam current and loss, and horizontal and vertical beam sizes (measured at sector 35 pinhole location). Using the hybrid-fill-mode lattice with linear chromaticity of 11 (for a single bunch current up to 20 mA), the following two experiments were performed with the initial condition of default operation sextupoles, which is optimized by MOGA simulations [7, 15].

- All sextupoles in 40 sectors (a total of 280 sextupoles, in 21 families): lifetime improved from 200 minutes to above 300 minutes; horizontal chromaticity reduced from 10.5 to 8.5; it is noted that the lifetime change is partly from chromaticity changes.
- S4 and S5 sextupoles only (a total of 14 sextupoles, in 14 families): lifetime improved from 200 minutes (88mA, coupling=0.66%) to 280 minutes (82mA, coupling=0.68%); small change on horizontal chromaticity (reduced from 11.4 to 10.8); vertical chromaticity slightly increased
- similar injection efficiency 60-65%

The sextupole current changing process takes relatively long time if all 280 sextupoles are included. For the case with S4 and S5 sextupoles only, the experiment was finished in a short time with 20 iterations, and 10 seeds for each iteration. The beam lifetime, horizontal and vertical beam sizes evolutions are shown in Figs. 2 and 3. The sextupole magnet current comparison is shown in Fig. 4. It is observed that the current change in sextupole magnets is moderate.

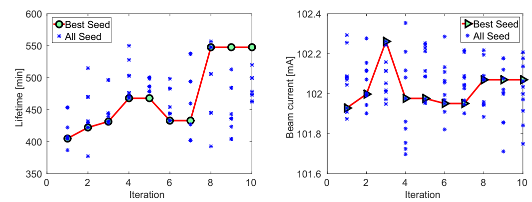

Figure 5: Topup mode, lifetime (left) and beam current (right) at each iteration. A total of 10 iterations, and 10 seeds for each iteration. Starting point is optimized sextupoles from MOGA simulation [7, 15] on the medium chromaticity lattice ($\xi = 6$).

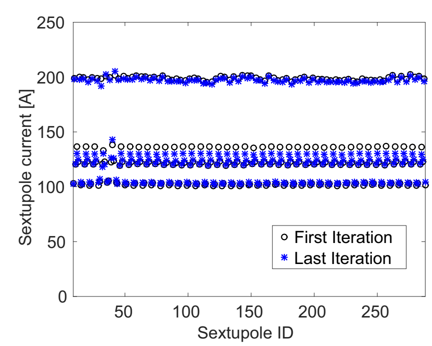

Figure 6: Topup mode, sextupole magnets strength for the first and last iteration, a total of 280 sextupoles in 40 sectors (21 families in total). Starting point is optimized sextupoles from MOGA simulation [7] on the medium chromaticity lattice ($\xi = 6$).

OPTIMIZATION FOR TOPUP MODE

The algorithm is designed to work with the topup operation mode. Nominally every 120 seconds there is a new injection bunch coming into the storage ring. The total beam current is maintained at 102 mA. The lifetime and beam current evolution are shown in Figure 5 for 10 iterations. In this example, all sextupole magnets in 40 sectors (a total of 280 sextupoles, in 21 families) are employed as knobs. The experiment takes several hours. The sextupole magnets strength for the first and last iteration is shown in Figure 6. The horizontal chromaticity is reduced by 1 unit and vertical chromaticity is increased by 1 unit, as listed below.

- Horizontal chromaticity reduced from 7.75 ±0.07 to 5.95 ±0.01.
- Vertical chromaticity increased from 5.34 ±0.09 to 6.47 ±0.06.

The topup injection efficiency varies significantly among these 100 seeds, as shown in Figure 7. The final choice is 72% which is slightly better than the initial value of 70%.

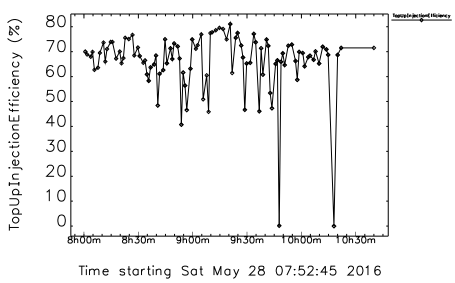

Figure 7: Top up injection efficiency during optimization.

COMPARISON AND DISCUSSION

Tracking simulations were performed to compare the nonlinear beam dynamics performance between the operation lattice and one of the online optimized lattices. It was found that these two lattices give similar chromatic detuning and dynamic acceptance, but slightly different local momentum acceptance, as shown in Fig. 8. It is observed that the online optimized lattice has improved local momentum acceptance.

Dispersion measurements illustrate that both horizontal and vertical dispersion functions are not changed much by the sextupole tuning process, as shown in Fig. 9. Horizontal dispersion functions are not shown here where the differences are negligible. Combined with the beam sizes measurement results presented above which show that the vertical emittance was not increased, it is concluded that the lifetime improvement may be from optimized nonlinear dynamics. The presented algorithm may be good at finding an optimum chromaticity setting for best lifetime for a given single bunch current, although it may reduce the safety margin for collective effects threshold.

CONCLUSIONS

Multi-objective online machine-based optimizations of beam lifetime was demonstrated at APS ring, for both beam current decay and topup operation modes. The lifetime improvement may be from nonlinear beam dynamics optimization. There are also some uncertain factors, such as changes in the chromaticity, and possible differences in the linear optics owing to orbit in sextupoles. Future studies

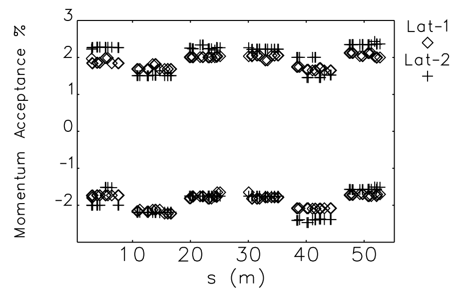

Figure 8: Comparison of simulated local momentum acceptance between the operation lattice (Lat-1) and one of the online optimized lattice (Lat-2).

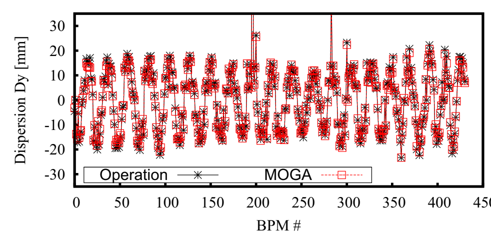

Figure 9: Comparison of measured vertical dispersion.

will add fixed linear chromaticities mode, measure the optics functions along the ring, and compare with detailed simulations.

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